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THE STONE REEFS OF BRAZIL, THEIR GEOLOGICAL AND GEOGRAPHICAL RELATIONS, WITH A CHAPTER ON THE CORAL REEFS.

BY JOHN CASPER BRANNER.

WITH NINETY-NINE PLATES.

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The Stone Reefs of Brazil, their Geological and Geographical Relations, with a Chapter on the Coral Reefs.

By John Casper Branner.

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I.

Introduction.

There is no more striking geologic phenomenon along the eastern shores of South America than the stone reefs of Brazil.

These reefs are supposed by many persons to be of coral, and this error has been propagated by writers of books of travels and by works on the navigation of the south Atlantic. There are several reasons for this error: coral reefs border many tropical coasts in a similar manner; there are extensive coral reefs on the coast of Brazil; the stone reefs of Brazil are unique, or rather they are found nowhere else in the world except on a very limited scale; seen from a vessel sailing along the coast or even near at hand, the stone reefs are scarcely distinguishable from coral reefs even by an expert; and, finally, the sandstone reefs are generally covered with calcareous growths common to coral reefs. The only thing that is especially characteristic of the form of stone reefs is their straightness, and this is not always apparent to one looking at them either from the shore or from the ocean. In Brazil the only men who really seem to know the difference between the two kinds of reefs are the lime-burners who make lime of the corals, and a few of the masters of *barcaças*, or sugar boats. Among these men distinction is made between the coral rock, which they know as *pedra de cal* (lime rock), or as *cabeça de carneiro* (sheep's head, referring to *Porites* and other solid heads), and the sandstone which they call *pedra de encantaría*; that is, stone used for window and door sills and facings, as the reef rocks have been used from the earliest times.

In a sense the sandstone reefs are local, but the forces and agencies that have formed them have been in operation along the entire coast, from near Maranhão to southern Bahia, while local conditions have prevented their formation at some places, or have favored their preservation or destruction at others.

The ports and towns behind the stone reefs owe everything to them. Without these reefs there would be no Pernambuco, no Rio Grande do Norte, no Porto Seguro, no Santa Cruz, to say nothing of the minor ports like Rio Formoso, Serinhaem, Suápe, Traição, Mamanguape, and many others where the sugar boats load and take refuge along the whole coast from southern Bahia to Ceará and Maranhão.

The geological and geographical peculiarities of these stone reefs consist in the facts that —

I. They are of sand consolidated to a hard — in places almost quartzitic — sandstone.

II. They stand about flush with the water at high tide, while at low tide they are left exposed like long, low, flat-topped walls, with a width of from five metres to one hundred and fifty metres, and a length of from a few paces to several kilometres.

III. They accompany the shore line with many and great interruptions from north of Ceará to Porto Seguro, a distance of two thousand kilometres.

IV. With unimportant exceptions the reefs do not occur along the Brazilian coast beyond these limits.

V. They usually stand across the mouths of streams and estuaries forming perfect natural breakwaters for the small harbors behind them. Sometimes they follow the shore, either on the beach or at a short distance from it.

VI. They are all nearly straight. When crooked, their curves are gentle.

VII. The structure and position of the reefs and the animal remains they contain show that they have been made by the lithification of beach sands in place.

VIII. When stone and coral reefs occur together, the stone reefs are inside or landward of the coral reefs. It is possible, however, that there may be buried coral reefs in some cases to the landward of some of the stone reefs.

IX. The coral reefs are now growing over and upon the stone reefs in some places, while at other places there are stone reefs overlying dead coral reefs.

X. In general appearance, elevation, and position the sandstone reefs bear a striking resemblance to the coral reefs.

My work on the reefs was begun in 1875–6–7, while I was a member of the Commissão Geologica do Brazil; it was extended at subsequent visits in 1881–2–3, and ended in June, July, August, September, and October, 1899, when an opportunity was afforded me by Dr. Alexander Agassiz to finish it. This last visit has been of the utmost importance, for I have thus been able to revise earlier and less trustworthy observations, to visit new localities, and also to study the problems that present themselves after a more thoughtful consideration of the whole subject.

Like so many of the problems that seem simple and easily disposed of at the outset, this one has turned out to be much less simple than was anticipated. And even now, after having worked at it for twenty-five years, I am more than ever impressed with the complexity, difficulty, and far-reaching nature of the problems surrounding these sandstone reefs. Above all, it seems evident that any satisfactory theory of these reefs must include the study of the geographic development of the coast-line, — a study not hitherto attempted. Certain theories that have been advanced in explanation of or in connection with these reefs are not discussed in the present paper because they are without the bases that would entitle them to serious consideration. One of these is the theory of their glacial origin.[1] It has already been shown that there is no satisfactory evidence of glacial action in Brazil.[2] Another is the theory of the orographic relations of the reefs to the western Alps. This idea was suggested to Liais by the once famous but now almost forgotten *Systèmes de Montagnes* of Élie de Beaumont.[3]

The problems of the coral reefs have long been before the scientific world. I have not been able to undertake any comprehensive study of the coral reefs of Brazil, but I hope that this approaching of the subject from the geological and geographical side may throw some light upon these problems, so far at least as this particular coast is concerned. In discussing the coral reefs I have endeavored to weigh the evidence at my command and to reach logical conclusions unbiassed by any particular theory.

There are several related topics which it was intended to discuss in connection with the ones here dealt with, such as the currents, winds, tides, submarine topography, and submarine erosion, but the paper is already too voluminous and those parts are omitted.

A great desideratum in studying the history of the Brazilian coast is a good topographic map. This does not exist. The hydrographic charts are the only ones available, but these deal only with such features as interest navigators, while the maps of the interior are often little more than vague generalizations. It is cause for congratulation that several of the Brazilian states under the lead of São Paulo, whose survey is headed by our able fellow-countryman, O. A. Derby, are undertaking topographic maps.

---

[1] Nouvelle géographie universelle. Par É. Reclus. Tome XIX. Amérique du Sud, p. 222. Paris, 1894.

[2] The supposed glaciation of Brazil. By J. C. Branner, Journ. Geol. I., p. 753–772.

[3] L'Espace Céleste. Par E. Liais, p. 544, 548. Comptes Rendus, 1860. L., p. 762–763.

Many kind friends have placed me under obligations by their cordial assistance in connection with this work. Mr. Whitaker, formerly President of the Geological Society of London, has helped me with valuable references. At Washington, Mr. Hay, Secretary of State, kindly furnished me with letters to the diplomatic and consular representatives of the United States in Brazil, and procured for me letters from the Brazilian minister at Washington to the governors of the Brazilian states to be visited.

In Brazil, the governors and the American representatives were extremely obliging; without their co-operation it would have been impossible to carry on my work. Mr. Guy Swift of Pernambuco, the former head of the firm of Henry Forster and Company at that place, has, by his high standing as a business man and his acquaintance with the country and the people, been of the greatest possible service. Mr. Kenneth C. Macray of Maceio, by his kindness and hospitality, made it possible for the expedition to accomplish at that place much that without such aid could not have been done.

As stated above, the last expedition in connection with this work was made in 1899, and was provided for by Dr. Alexander Agassiz. I was accompanied by several volunteer assistants: Ray Collins, B. H. Collins, Harold Havens, and C. E. Gilman, at that time students of geology in Stanford University. Mr. Gilman made most of the maps of special areas. My principal assistant was Dr. Arthur W. Greeley, now of Washington University, at St. Louis, who had entire charge of the biologic work. Dr. Greeley prepared the paper on the corals at the end of this report. The materials collected by him were sent to specialists, and the following papers have already been published upon them by the Washington Academy of Sciences: "Crustacea" by Mary J. Rathbun; "Isopod Crustacea," by Harriet Richardson; "Mollusca," by W. H. Dall; "Fishes," by C. H. Gilbert.

The original maps accompanying this paper — those by Messrs. Gilman and Havens — were made with a six-inch compass needle for taking bearings, while distances were either paced or determined by triangulation. The long reefs were all paced; the isolated rocks were located by triangles.

II.

Sketch of the Geology of the Coast in its Relations to the Stone and Coral Reefs.

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The discussion of the stone reefs of Brazil is both a geological and a geographical one. It is therefore necessary to get our geological orientation, — to have some idea of the general geological history of the region discussed, before treating of the reefs themselves. This is essential, because the reefs are of late geological origin, and it is necessary to understand the geological history of the coast in order to see where the reefs came into that history. It is also the more necessary on account of many statements in the present paper that do not agree with earlier publications regarding the geology of the region here treated.

Pre-Cretaceous. — The principal feature of the coast geology with which we have to deal is a series of mechanical and organic sediments forming a plateau along nearly the whole of the coast from the northern part of the State of Rio Grande do Norte to the State of Espirito Santo, — a distance of nearly two thousand kilometres. Over most of this distance these sediments rest upon crystalline rocks, — in some places granites, in other places gneisses, in others schists. These old crystalline rocks are cut here and there by eruptive dikes of later age. The age of the old underlying beds is not known, but the schist series looks very like the Algonkian of Van Hise. At one place — the Serra of Itabaiána, in the State of Sergipe — there are older sediments between the crystalline rocks and the later sediments known to be of Cretaceous age. No fossils have been found in these lower beds, but from their position below the Cretaceous beds they have been provisionally assigned to the

Palaeozoic.[1] They might with just as much propriety, however, be referred to the Jurassic or Triassic. So far as the present discussion is concerned, the age of these pre-Cretaceous beds is a matter of but little importance. Our present interest is chiefly with the Cretaceous and with the post-Cretaceous history.

The Cretaceous. — There are marine Cretaceous beds in the State of Sergipe resting upon the Palaeozoic and crystalline rocks of the interior, but how far north and south these beds extend is not known at present. It is quite possible that a narrow strip of Cretaceous rocks extends up and down the coast for a long distance, and it is possible, too, that the bottom part of the series here set down as Eocene is really Cretaceous.

What is the age of the Bahia beds? — There has been some confusion in the classification of the Cretaceous and Tertiary beds of the east coast of Brazil. It is necessary, therefore, to bring together the evidence upon which the classification is based, and to ascertain, if possible, which beds are Cretaceous and which Tertiary. Without entering into details it may be accepted as satisfactorily proved that the highly fossiliferous beds of the Sergipe basin are Cretaceous. The fossils from these beds are described by Dr. C. A. White in his excellent monograph.[2] Some of the other beds, however, have been referred to both Cretaceous and Tertiary. Inasmuch as the rocks of the Bahia sedimentary basin have yielded more palaeontologic evidence than any one locality outside of Sergipe, the age of the beds of that region will be considered first and in more detail. It is with these that we now have to deal.

The earliest paper in which a definite geologic age is assigned the coast sediments is one by J. F. M. Von Olfers, published in "Karsten's Archiv für Mineralogie, etc.," IV. 173–180, at Berlin in 1832 under the title, "Ueber das niedrige Felsenriff der Küste von Brasilien." In this paper the author puts down as Tertiary the stone reefs, the sandstones of the Amazon valley, the rocks of the Bahia basin, and all the sedimentary beds from Maranhão to the Abrolhos. He makes no mention, however, of any palaeontologic evidence of the ages of any of these rocks.

In 1836 Charles Darwin touched at Bahia, and though he does not give their names, he speaks of having found Tertiary fossils at the head of the Bay.[3]

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[1] J. C. Branner, the Cretaceous and Tertiary geology of the Sergipe-Alagôas Basin. Trans. Amer. Phil. Soc., XVI., p. 381–382. Philadelphia, 1889.

[2] Archivos do Museu Nacional, VII. Rio de Janeiro, 1887.

[3] Charles Darwin, Geological observations, 2 ed. London, 1876, p. 193, foot-note.

In 1842 M. A. Pissis presented to the French Academy of Science a paper on Brazilian geology,[1] in which he speaks of the Bahia sediments as both marine and fresh-water Tertiary. The only mention Pissis makes of palaeontologic evidence is (p. 398) that the beds contain fossil pectens, oysters, and cythereas, — genera which later collectors have not found there, and which, if found, would not alone fix the Tertiary age of the beds.

In 1859 Prof. T. Rupert Jones described a small collection (five species) of Entomostraca from Bahia. Professor Jones said of these fossils that they appear to be allied to recent and Tertiary species. In the same place S. Allport describes vertebrate remains from the Bahia beds, among which are the scales of *Lepidotus*. These two papers of Allport and Jones are the first we have that afford definite palaeontologic evidence of the age of the Bahia sediments. Unfortunately the evidence is conflicting from the very beginning: the Entomostraca are allied to recent and Tertiary species, while the *Lepidotus* is a Cretaceous species.[2]

In 1869 Marsh described[3] from the Bahia basin *Crocodilus harttii*, which he says resembles a species from the Miocene of Virginia, and another from the Tertiary of New Jersey.[4] Another fossil vertebrate, *Thoracosaurus bahiensis*, he says, is probably allied to the modern gavials.

In 1870 Hartt's book on the geology of Brazil[5] appeared, in which he speaks of the beds of the Bahia basin as lower Cretaceous (p. 350), and possibly Neocomien (p. 555). He describes from these beds a few new fossils, and gives much data upon the details of geologic structure about the Bahia basin, but there is nothing that can be regarded as having diagnostic value in a doubtful case, and no palaeontologic evidence to warrant the reference of some of the beds to the Lower Cretaceous and others to the Tertiary (p. 377).

---

[1] Mémoire sur la position géologique . . . de la partie australe du Brésil. Mém. de l'Institut de France, X. p. 353–412.

[2] On the discovery of some fossil remains near Bahia in South America. S. Allport, T. Rupert Jones, Note on the fossil Entomostraca from Montserrate. Quarterly Journal Geological Society, December, 1859, XVI., p. 263–268. London, 1860.

[3] O. C. Marsh, Notice of some new reptilian remains from the Cretaceous of Brazil. Amer. Journ. Sci., XCVII., p. 390–392. New Haven, 1869.

[4] Dr. A. Smith Woodward notes that this is a detached tooth, and should not be considered in this connection. (Private letter, Nov. 7, 1902.)

[5] Ch. Fred Hartt, Geology and physical geography of Brazil. Boston, 1870.

In 1886 Cope described vertebrate fossils from Bahia.[1] One of these — a fish, *Diplomystus* — had not hitherto been known below the Green River Eocene of North America, but has since been found in the Cretaceous of Lebanon, Syria, and now living in the rivers of Chili and in New Zealand. A mammal, *Toxodon expansidens*, from the northeastern part of the State of Bahia, is set down by him without question as of Pliocene age, but this without doubt comes from beds other than those referred to the Cretaceous.

In 1887 Dr. C. A. White's great work on Brazilian fossils was published.[2] The Bahia basin is there set down as Cretaceous. In reviewing the palaeontologic evidence bearing upon this subject, Dr. White says that only eleven species of mollusks are known from the Bahia beds, and he makes this important observation (page 233): "*All the types which this fauna embraces, so far as they are determinable, are represented among mollusks now living.*"

In 1888 Dr. A. Smith Woodward published notes on fossils from these beds,[3] in which he mentions the occurrence of *Diplomystus longicostatus* Cope; *Chiromystus mawsoni* Cope; *Lepidotus mawsoni* Woodward; *Acrodus nitidus* Woodward.

In 1891 Dr. Woodward published evidence[4] of the occurrence of Pterosaurians and Plesiosaurians in the Bahia beds. In 1895 he described two species of *Diplomystus* from the same basin;[5] in 1896 he described from there a Pterodactyle bone,[6] and in 1902 he described *Megalurus mawsoni* from the Bahia beds.[7]

Of these vertebrate fossils reported by Dr. Woodward, the Pterosaurians suggest that the beds are either Jurassic or Cretaceous; the Plesiosaurians suggest that they are Jurassic; the *Diplomystus* suggests that they may be anywhere from Cretaceous to recent; the *Pterodactyle* suggest that they are certainly Cretaceous or older; and the *Megalurus* that they are Upper Jurassic.

Conclusion regarding the Bahia beds. — The papers by Dr. Woodward afford the latest and by far the most conclusive palaeontologic evidence of the age of the Bahia beds, and this evidence certainly points to their Cretaceous or even earlier age. The evidence favoring the Tertiary age of the beds, however, cannot be overlooked. Without the vertebrate fossils we should have been compelled to call the Bahia sediments Tertiary. When, however, all the data now available are taken into consideration, one of the following solutions to the problematic combination seems possible: —

---

[1] E. D. Cope, A contribution to the vertebrate paleontology of Brazil. Proc. Amer. Phil. Soc., 1886, XXIII., p. 1–21.

[2] Contribuições á Paleontologia do Brazil. Archivos do Museu Nacional, VII. Rio de Janeiro, 1887.

[3] A. Smith Woodward, Notes on some vertebrate fossils from the province of Bahia, collected by Joseph Mawson. Ann. Mag. Nat. Hist., ser. 6, II., p. 132–136. London, 1888.

[4] Ann. Mag. Nat. Hist., ser. 6, VIII., p. 314–317.

[5] *Op. cit.*, ser. 6, XV., p. 1–3.

[6] *Op. cit.*, ser. 6, XVII., p. 255–257.

[7] *Op. cit.*, ser. 7, IX., p. 87–89.

I. It is possible that there are two or more well-defined formations (Cretaceous and Tertiary, and possibly others), but that for lack of proper stratigraphic and palaeontologic work they have not been defined and separated.

II. It is possible that both Cretaceous and Tertiary are represented, but that there is no stratigraphic or faunal break between them in that region.

III. It is possible that in Brazil we have a fossil fauna unlike any that characterizes either Cretaceous or Tertiary of other parts of the world; that is, that some of the Tertiary forms of North America began during Cretaceous times in Brazil, or that the Cretaceous forms of other parts of the world survived into the Tertiary in Brazil.

I was formerly disposed to think the first suggested solution the correct one. The little I have seen of the Bahia basin inclines me to think that the beds containing fossil Mollusca near the Montserrate fort overlie and are northwest of the beds yielding most of the vertebrate fossils. The latter beds contain heavy conglomerates at the base and rest against the granites. But whether beds of two separate ages exist on the coast of Brazil or not, studies of the living molluscan and coral faunas of the Brazilian coast and their comparison with the faunas of Florida and the West Indies lead to the inference that our gulf fauna came originally from the coast of Brazil. (See Dall on Mollusca and Verrill on corals.)

It seems not improbable therefore that the Tertiary fauna of the Gulf States may have originated in a similar manner on the coast of Brazil, and that in migrating northward it has undergone changes that have caused it to diverge somewhat from its parent stock, while the Brazilian fauna of the same age may have retained some of its Cretaceous aspects.

Since the above was written I have asked the views of Dr. A. Smith Woodward. In reply to an inquiry regarding his conclusions based upon the vertebrate fossils he writes under date of Nov. 7. 1902: "I consider that *Lepidotus*, *Acrodus*, Dinosaurs, and Pterodactyls prove that the Bahia sandstone fauna is Mesozoic. There is, of course, some reason to suspect that Dinosaurs lived later in South America than elsewhere. (See Proc. Zool. Soc., 1901, I. 182.)"

The age of other coast sediments. — The above conclusions are based upon materials from the Bahia basin. How far they are applicable to the other regions, — that is, to the Pernambuco, Parahyba do Norte, and Pará regions, — hitherto set down as Cretaceous, it is not possible at present to say. Some of the Bahia beds are of fresh or brackish water origin; it is therefore difficult to correlate them with marine beds in distant parts of the country, and it is necessary to consider separately the evidence found outside of the Bahia basin.

As has already been pointed out, Olfers called all these coast sediments Tertiary, but he says nothing of palaeontologic evidence. In 1836 Darwin examined the sedimentary beds near Pernambuco and speaks of them as Tertiary,[1] but he says that he looked in vain for organic remains in them.

In 1846 George Gardner considered the sedimentary beds at Rio Formoso on the Pernambuco coast to be Cretaceous like those of the interior of Ceará,[2] but as he reported no fossils from them no importance was attached to his opinion.

Fossils have now been found in the coast sediments (outside of the Sergipe and Bahia basins) at the following places: Olinda (Hartt, Branner), Maria Farinha (Hartt, Derby, Branner), Itamaracá (Branner), Ponta de Pedras (Branner), Parahyba do Norte (Capanema, Agassiz, Sumner), Jacumã (Branner); in the State of Rio Grande do Norte at Mossoró (?) and Apody; and also at Pirabas (Penna) in the State of Pará. In addition to these stations fossils have likewise been found at a few points in the interior of Parahyba do Norte and of Rio Grande do Norte.[3]

In 1859 the "Commisão Scientifica" of Brazil touched at Parahyba and Barão de Capanema says: "A badly preserved crinoid leads me to suppose that the rock belongs to the Cretaceous."[4]

In April, 1867, E. Williamson read before the Manchester Geological Society a paper upon the geology of Parahyba and Pernambuco,[5] in which he says there are Tertiary and Cretaceous rocks in the region, and he seems to mean that the upper colored beds somewhat resembling the New Red Sandstone of England are Tertiary, and that the impure limestones beneath them are Cretaceous. He mentions no fossils, however, and gives no reason for calling either of the series by these names.

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[1] Charles Darwin, Geological observations, 2 ed. London, 1876, p. 193.

[2] George Gardner. Travels in the interior of Brazil, p. 103–104. London, 1846. Rio Formoso is not specifically mentioned by Gardner, but his observations regarding the locality and his notes upon the voyage leave but little doubt about that being the place referred to.

[3] Bull. Geol. Soc. Amer., XIII., p. 56–57.

[4] Trabalhos da Commissão Scientifica de Exploração I Secção Geologica, p. CXXII. Rio de Janeiro, 1862.

[5] E. Williamson, Geology of Parahyba and Pernambuco gold regions. Trans. Manchester Geol. Soc. 1866–67. VI., p. 113–122.

In 1865, Prof. Louis Agassiz touched at Parahyba do Norte, and Hartt states that he found there fossil estherians from which he (Hartt) infers that the deposits are of fresh-water origin and equivalent to the Bahia beds which he regarded as of Cretaceous age.[1] This, however, was not published until 1870.

Later Hartt set off from the beds later accepted as Cretaceous an upper and apparently a well-differentiated series of highly colored and mottled beds, and called them Tertiary. This scheme first appeared in 1868,[2] but was treated more fully in his book that appeared in 1870,[3] and again in a paper read before the American Geographical Society in 1871.[4]

This designation of the colored beds, afterwards known as the Tertiary, commended itself so favorably to field geologists in Brazil that it was immediately accepted,[5] though Hartt himself observed afterwards that "one may find variegated clays on the Amazonas containing Devonian and Carboniferous fossils.[6] And yet no one ever succeeded in all the thousands of kilometres of exposure in finding a single well-defined line of division between the Cretaceous and the supposed Tertiary beds,[7] and no one found a fossil in the so-called Tertiary ones, with the possible exception of the fossil plants found within the last few years in the State of Bahia, the age of which has not yet been determined. But aside from these two important wants, the assignment of the horizontal colored upper beds to the Tertiary appeared to be a proper one, and no especial difficulty seemed to be encountered in dealing with them as such. From 1870, when Hartt's book was published, down to the present time, these unfossiliferous party-colored beds have been called Tertiary.

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[1] Geology and physical geography of Brazil, p. 445.

[2] C. F. Hartt. Résumé of a lecture on the growth of the South American continent, p. 5. Reprinted from the *Cornell Era* of Dec. 12, 1868. Ithaca, N. Y., 1868.

[3] C. F. Hartt. Geology and Physical Geography of Brazil, p. 557. Boston, 1870.

[4] Ann. Rep. Amer. Geogr. Soc. Vol. III., p. 231–252.

[5] The present writer published in 1889 a paper upon the Cretaceous and Tertiary geology of the Sergipe-Alagôas Basin of Brazil. (Trans. Amer. Phil. Soc., XVI., p. 369–434) in which he followed Hartt's division.

[6] Amer. Journ. Sci. 1872. CIV., p. 57.

[7] Both Hartt and Williamson say the Tertiary overlies the Cretaceous unconformably. Geol. and Phys. Geogr. of Brazil, 557; Résumé of a lecture on the growth of the South American continent (Ithaca, N. Y., 1868), p. 5. Trans. Manchester Geol. Soc., 1866–67, VI., p. 114.

In 1875 Richard Rathbun published a paper upon the lamellibranchs found in the vicinity of Pernambuco.[1] The materials were from three localities in the vicinity of Maria Farinha, eighteen miles north of Pernambuco. Although the title of Mr. Rathbun's paper shows that the beds were regarded as Cretaceous, all the species in his list are new except two; and among those described are *Cucullæa harttii* and *Venericardia* (*Cardita*) *morganiana*, which, if found in North America, would be regarded as Tertiary.

In Dr. White's monograph published in 1887 are described more fully the molluscan collections from Maria Farinha in the State of Pernambuco, and from Pirabas,[2] State of Pará. The localities yielding these fossils are likewise set down by White as Cretaceous in spite of the fact that they contain such characteristic Tertiary forms as

Hercoglossa (*Nautilus*) sowerbyana d'Orb.
Volutilithes radula (Sowerby) Forbes.
Mazzalina (*Fasciolaria*) *acutispira* White.
Pseudoliva (*Harpa*) *dechordata* White.
Cucullæa harttii Rathbun.
Calyptraphorus ? chelonites White.
Venericardia (*Cardita*) *morganiana* Rathbun.

It cannot be denied, however, that some of the fossils from Maria Farinha are of decided Cretaceous aspect.

When Dr. White undertook the study of the Brazilian Cretaceous (and Tertiary) fossils collected by the Commissão Geologica it was expected that he would remove any doubts that might exist in regard to the ages of the formations represented. But instead of weighing the evidence and reaching an independent conclusion, he accepted without question the earlier inference of Hartt. I would not imply that Dr. White failed to do his duty in this matter. The fact is that the collecting was not done so that he could have made a separation of the faunas if it had been otherwise possible. I say this the more frankly because most of the fossils described by him were collected by me. But at that time I was altogether unacquainted with the distinction between Cretaceous and Tertiary fossils, and I knew next to nothing of the care and discrimination required in such collecting. I now recall the fact that at one of the Maria Farinha localities I sifted fossils out of piles of residuary earth that might have represented several different formations, and all of these went to Dr. White simply as having come from Maria Farinha.

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[1] Richard Rathbun. The Cretaceous Lamellibranchs collected in the vicinity of Pernambuco, etc. Proc. Boston Soc. Nat. Hist., XVII., p. 241–256. Boston, 1875.

[2] In Dr. White's Contributions this place is called Piabas, but a later paper by Drs. Huber and Kraats, who visited the locality in 1898 (?) shows that the correct name is probably Pirabas.

At a place on the northern coast of the State of Pernambuco called Ponta de Pedras I found sedimentary beds containing fossils that strongly resemble those found at Maria Farinha. These fossils were examined by Dr. Ralph Arnold, who kindly made the following determinations and correlations: —

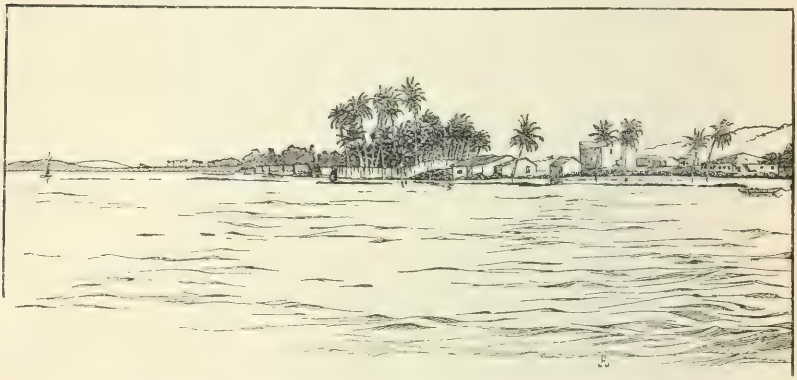

Fig. 1. Ponta de Pedras, State of Pernambuco. The fossiliferous rocks are exposed along the beach.

Fossils from Ponta de Pedras, Coast of Pernambuco.

		Also found at —
1.	*Cypræacteon pennæ* White	Rio Pirabas.
2.	*Volutilithes radula* (White, not Sowerby)	Olinda; Maria Farinha.
3.	*Volutilithes alticostatus* White ? *V. radula* White	Maria Farinha.
4.	*Acmæa* sp. nov.	
5.	*Natica* or *Neverita* sp. undet	Montserrate, Bahia.
6.	(*Neritina prolabiata* White)	
7.	*Turritella elicita* (White, not Stolitzka)	Maria Farinha.
8.	*Vicarya ? daphne* White	Maria Farinha.
9.	*Capulus* sp. nov.	
10.	*Amalthea* sp. nov.	

	Also found at —
11. ? *Melania terebriformis* Morris ?	Itamaracá; Montserrate, Bahia.
12. *Crepidula* sp. nov.	
13. *Lucina tenella* Rathbun	Rio Pirabas; Maria Farinha.
14. *Nucula mariœ* Rathbun	Maria Farinha.
15. *Leda* (*Nuculana*) *swiftiana* Rathbun	Maria Farinha.
16. *Corbula* ? *chordata* White	Maria Farinha; Sergipe; Rio Pirabas.
17. *Corbula* sp. nov.	
18. *Dosinia brasiliensis* White	Sergipe; Rio Pirabas.
19. *Glycymeris* (*Axinea*) *bineminis* White	Rio Pirabas.
20. *Cardium* (*Criocardium*) *soaresanum* Rathbun	Maria Farinha; Itamaracá.

Of the twenty species here listed, five are new, five are reported from Rio Pirabas, State of Pará, nine are found at Maria Farinha, two at Montserrate, Bahia, two in the State of Sergipe, and one at Olinda, Pernambuco. Two were also found at a new locality discovered by the writer at the northeast end of the island of Itamaracá. The specimen from Itamaracá was found in a bed of brown sandstone. The Itamaracá locality is only eleven kilometres south, and Maria Farinha is only twenty-seven kilometres south of Ponta de Pedras.

The resemblance of the fauna found in the Ponta de Pedras rocks to that of the Maria Farinha beds is at once apparent, while the proximity of the localities to each other bears out the theory that the same beds are repeated at these two or three localities.

At Parahyba do Norte, on the other hand, have been found a few fossils, one of which — a species of *Sphenodiscus* — is so characteristic a Cretaceous genus that it seems impossible to doubt the Cretaceous age of the beds from which it came.[1] The same beds have yielded a species of *Cimolichthys*, another Cretaceous genus.

On account of his acquaintance with South American palaeontology I have asked the opinion of Dr. A. E. Ortmann of Princeton regarding the possible Tertiary age of some of the beds yielding the fossils described by Dr. White. He writes me as follows: —

PRINCETON, N. J., 27 July, 1902.

DEAR SIR, — Thanking you for your letter of May 9th I may say that I have used White's paper on the supposed Cretaceous in Brazil for comparison with my Patagonian fossils; but, of course, I did not make a very careful search for allied species, since I took it for granted that we have to deal here with Cretaceous beds.

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[1] Bull. Geol. Soc. Amer. XIII., p. 43.

But since you called my attention to the probable Tertiary age of at least a part of these deposits, I have examined the matter more closely. I find that your contention that part of these beds is Tertiary (Eocene) is well supported, and am fully prepared to accept this view.

Among the fossils, there are not many that show affinities to our Patagonian (Miocene) forms, which is probably due to their older age (Eocene). But nevertheless there are a few relations. The following are the most striking.

Ostrea distans White, from Pará. This is a characteristic Tertiary type, allied to our *O. ingens* Zitt.

Gryphaea brachyoptera White, from Pernambuco, resembles *G. tarda* Hutt, from the Patagonian beds.

Cardita wilmotti Rathbun, from Pernambuco and Pará, resembles *C. inaequalis* Phil.

Posinia brasiliensis White, from Sergipe, Pará, and Pernambuco, is *very* near *D. magellanica* Ortm. from the Magellanian beds of Punta Arenas.

Trochus retectus White, from Pará, resembles *Calliostoma garretti* Ortm.

Fusus pernambucensis White, from Pernambuco, comes near *F. subspiralis* Ortm. from the Magellanian beds of Punta Arenas.

Calyptraea fausta White, from Pará, comes near *Crucibulum dubium* Ortm.

It is very significant that we have two species (*Posinia brasiliensis* and *Fusus pernambucensis* which resemble most closely species described by myself from the Magellanian beds, which I take for Oligocene. This would furnish additional evidence for the old Tertiary age of the Brazilian beds, and, on the other hand, for the similar age of the Magellanian beds.

Yours very truly, A. E. ORTMANN.

In view of his acquaintance with the Eocene of North America I have asked the opinion of Prof. Gilbert D. Harris of Cornell University regarding the fossils from Maria Farinha and Pirabas, Pará. Dr. Harris writes me as follows: "I can assure you most emphatically that neither in that work (Dr. White's report on the Brazilian Mesozoic fossils) nor in our specimens (at Cornell University) nor in those I have seen in the United States National Museum from Maria Farinha, can I find a trace of any fauna other than the Midway Eocene."

The relation of color to age. — It has already been stated that Hartt regards the party-colored beds of the coast of Brazil as Tertiary, and that this long seemed to be a fairly satisfactory method of disposing of them.[1] The fact that these colored beds always seemed to be horizontal, while the Cretaceous strata were usually more or less bent, appeared to give support to this classification.

The horizontal bedding of these rocks is sometimes more apparent than real, and as the apparent bedding is associated with the coloring, these features of the series may be treated together. Seen from several miles at sea, the horizontality of the colors sometimes gives the rocks the appearance of having horizontal beds, when in reality the colors cut across the beds. At the colored cliffs just south of Rio Camaragibe in the State of Alagôas this can be seen fairly well. The bluffs at that place are from seventy-five to one hundred metres high and the upper part is all highly colored. Plate **11** is taken at this locality from a platform of unaltered rocks shown in the foreground that is covered at high tide, when the water reaches the face of the steep bluff. These beds dip gently toward the right at an angle of from 5° to 8°. Attention is directed to a fairly well-defined light-colored band that runs along the top of the steeper part of the bank. This band is the lower limit of the colored portion of the rocks in these hills, and it can be seen even in the photograph that the line of discoloration is horizontal, while the beds have a gentle but decided dip. Above the line of discoloration the rocks are colored and mottled soft clays and sands, mixed in all sorts of proportions, but whose bedding is more or less difficult to trace. These are the rocks we have been in the habit of calling Tertiary. Below the horizontal band they have their bedding perfectly defined, and vary from coarse sandstones to fine compact shales, in color mostly grays of various shades, and dark brown to almost black. They have limy streaks in them here and there, and the shales often have a lumpy or concretionary appearance. The unaffected parts of these beds are only from five to seven metres above tide, and the top of the unweathered portion retains this elevation regardless of the dip of the beds.

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[1] Geology and physical geography of Brazil, p. 557. Ann. Rep. Amer. Geog. Soc., III., p. 231–252.

The line separating the colored and the uncolored portions is not a clean-cut one. The unaffected beds can be traced upward into and across this line; but the change is a very gradual one — it is only when one stands away from the exposure and tries to trace out the individual strata with the eye that he cannot do it.

Plate **12** is another view that shows well the bedding of these Cretaceous shales and sandstones at the same place. The lower portion of the bluff is washed by the sea at high tide, and up to a height of six metres these beds are dark and light grays. The top of the bluff where the plants grow is decomposed and highly colored. The rocks dip away from the observer at an angle of 14°, and just round the corner shown on the left the line of discoloration cuts the tops of the series along an approximately horizontal plane.

At the northern end of this exposure are many large water-worn granite boulders apparently weathered from a basal conglomerate.

Going south along the coast from the Barreira do Camaragibe before reaching the town of Santo Antonio da Barra Grande, one finds some beautiful examples of coloring. The bluffs — there are several of them — are about fifty metres high, and the rocks are red, pink, gray, white, yellow, purple, orange, black, brown, and streaked and mottled, — all combined to make a most brilliant bit of rock coloring. In the upper part of this bluff the bedding planes cannot be made out, and even the colors appear only in irregular blotches, streaks, and bands. But at the base of the cliff there are some beds still clearly defined as shales and sandstones.

At one place the upper part of the section is all gray and cream-colored, while the lower part is fantastically splotched and streaked. A coarse-grained sandstone is partly of a pearl-gray color with a vast number of sharply defined streaks and rings of brilliant cinnabar red running through it. At two places the beds seem to be faulted, and where the faults appear there are masses of unbedded white or gray sandstone harder than the other rocks. These masses of sandstone have the appearance of vertical intrusions.

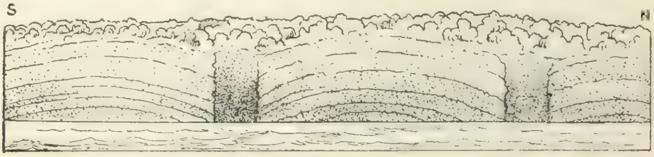

FIG. 2. Bluffs of party-colored sandstones and shales fifty metres high north of Santo Antonio Grande, State of Alagôas.

The exposure that first led me to question the validity of the so-called Tertiary division of these rocks is at a place on the Alagôas coast known as the Barreira do Boqueirão, a few miles north of the mouth of Rio Manguába.

The following sketch (page 21) will give some idea of the geological relations there exposed.

The hills at Barreira do Boqueirão are some seventy metres high, and the dip of the rocks is mostly toward the hills. The upper part of the hills is of red, brown, purple, and yellow clays and sands nowhere clearly separated from each other. To the left is a bed of fossiliferous bituminous shales, exposed for a distance of 150 metres, and dipping from 10°

to 15° N. 45° W. beneath the hill. It overlies the strongly bedded conglomerates and sandstones exposed on the right. The dip is not constant, however, for one hundred and fifty metres down the shore the dip is more nearly west. The exposure of the bituminous shales shows them to be nearly two metres thick, but it is possible that they have a thickness of three or four metres.

Now the lower or left (south) end of this shale is a fossiliferous peaty or bituminous bed with limy streaks and patches in it, while the upper or right end merges into a mass of mushy nondescript purple and brown sandy clays. Further, the discoloration has progressed more rapidly in the sandstones beneath the shales than in the shales, so that the former are already mottled and stained to a depth of six metres or more below the base of the shales. It should be added that the conglomerates of this section contain water-worn granite boulders as large as a man's head.

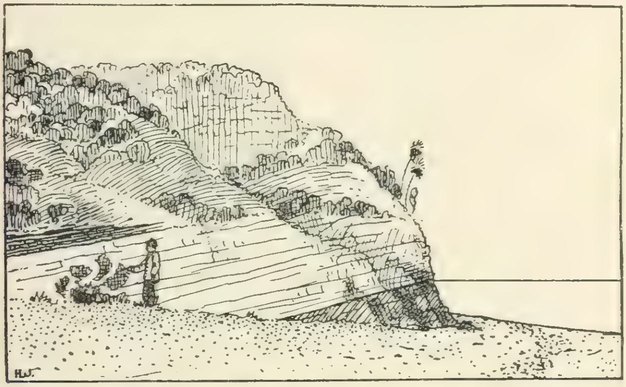

FIG. 3. Exposure on the beach at Barreira do Boqueirão.

At the City of Maragogý, State of Alagôas, only fourteen kilometres north of the Barreira do Boqueirão, a section is exposed at the base of the hill in the rear of the church. Here the bottom stratum, perhaps not more than five or six metres above tide, is false bedded and mottled so that it strongly resembles the bottom bed at the Barreira do Boqueirão.

At Riacho Doce (S. lat. 9° 36′), the shales and sandstones are exposed from the mouth of the stream southward nearly to Garça Torta. As in many other places, they are cut off by the waves so that they are well exposed only at low tide. They are much bent and faulted at this place, here covered by patches of coral reefs and there by fragments of sandstone reefs. These beds also seem to lie close to the base of the series, for about the mouth of Riacho Doce and scattered among the exposures are big granite boulders, many of them more than a metre in diameter, apparently weathered or washed from a heavy basal conglomerate.

The bituminous shales at Riacho Doce are fossiliferous, containing abundant diatoms, plant fragments, and fish remains. The diatoms are fresh-water forms, while the land plants are too fragmentary for identification. One fossil fish was identified by Mr. F. A. Lucas of the U. S. National Museum as *Diplomystus laticostatus* Cope, a form that is found also at Bahia.

The dips of the beds vary greatly in amount and considerably in direction, but the general direction is landward, — toward the red bluff that rises on the west. This bluff is a beautiful example of the weathered sediments; it is about a hundred metres in height, half a kilometre or more in length, and is most brilliantly colored. Seen from the beach half a kilometre away, the beds appear to be horizontal.

A noticeable feature of the dips at all the exposures on the coast is that they are *landward*. A section at Riacho Doce would fit most of the cases thus far seen.

Some of the most accessible localities at which these beds are to be seen are at and about the city of Olinda near Pernambuco. There is a good exposure at Olinda about a hundred metres northwest of the Varadouro station in the rear of a wine factory. Here the beds are horizontal, lumpy, yellowish rocks containing fossils; the exposure is at the base of the hill, and the thickness visible is six or seven metres. My friend, Dr. Louis Lombard, formerly Director of the Escola de Engenharia of Pernambuco, showed me some fossils collected by him from beds exposed on the Olinda beach at low tide.

The hill on which the Carmo church stands is of mottled beds toward the top, while near the base small patches of the yellowish fossiliferous rock appear here and there. On the slope of the hill below the Church of São Francisco the mottled and the yellow limy rocks are mingled in a newly opened drainage ditch.

About a kilometre west of Olinda are some typical exposures of the colored beds known as the Ruinas de Palmira. These "ruins" are at about the same elevation as the upper parts of the Olinda hills.

At Maria Farinha limy fossiliferous beds are exposed about the bases of all the hills near the mouth of the river and along the estuary for several kilometres, but in all the hill-tops the rocks are red and yellow and mottled, and these colors descend on the slopes of the hills almost or, in places, quite to tide level. Though I have been over these hills many times and carefully searched for the contact between what were formerly considered to be Cretaceous and Tertiary beds, I have never succeeded in finding anything suggesting a line of division.

The Island of Itamaracá has limestones and calcareous sandstones exposed about its lower levels, but its hill-tops are capped with the weathered red beds. I found fossils in the lowest beds at tide-level, on the northwest corner of the island, but I could find no dividing line between these and the red and yellow earths that cap the hills on this corner of the island. Dr. Louis Lombard showed me Cretaceous cephalopods collected by him near the southwest end of the island from the limestone, and I was told of several lime-kilns about the place, but over the island generally the hill-tops are of red and yellow soil.

At the point of land about a kilometre south of Jacumã on the coast of the State of Parahyba do Norte, the rock exposed at the water's edge is yellow fossiliferous calcareous sandstone like that at Itamaracá. Within a distance of two hundred metres of the fossiliferous beds the sea has exposed overlying colored strata at as low a level or lower, but no dividing line can be seen between the two. They merge imperceptibly into each other.

At Parahyba the fossiliferous Cretaceous beds are exposed near the railway station in the cuts along the line leading to Cabedello, while the tops of the hills on which the city is built are of the red and mottled weathered beds. I naturally hoped to find in this railway cut, made since my first visit to Parahyba, the contact between Tertiary and Cretaceous, but, as elsewhere, the two divisions merge together so imperceptibly that no separation can be made out though the exposure is a fairly good one.

The colored beds cap the hills on which the city of Parahyba stands, and continue eastward to Cape Branco, where they are well exposed upon the beach.

In Bahia between Jaguaripe and Nazareth there are pinkish horizontal sandstones that, according to our former classification, were included in the Tertiary, but north of São Thomé on the shores of the bay, similar sandstones have a north dip of from ten to fifteen degrees. These beds are pink in the hill-top, but lose that color as they approach and pass below tide-level.

This case is worthy of attention, as showing also that horizontality which we formerly regarded as characteristic of the Tertiary in Brazil has no diagnostic value. So far as I know, the Tertiary beds of this coast are nearly all horizontal, but the horizontal beds are by no means all Tertiary.

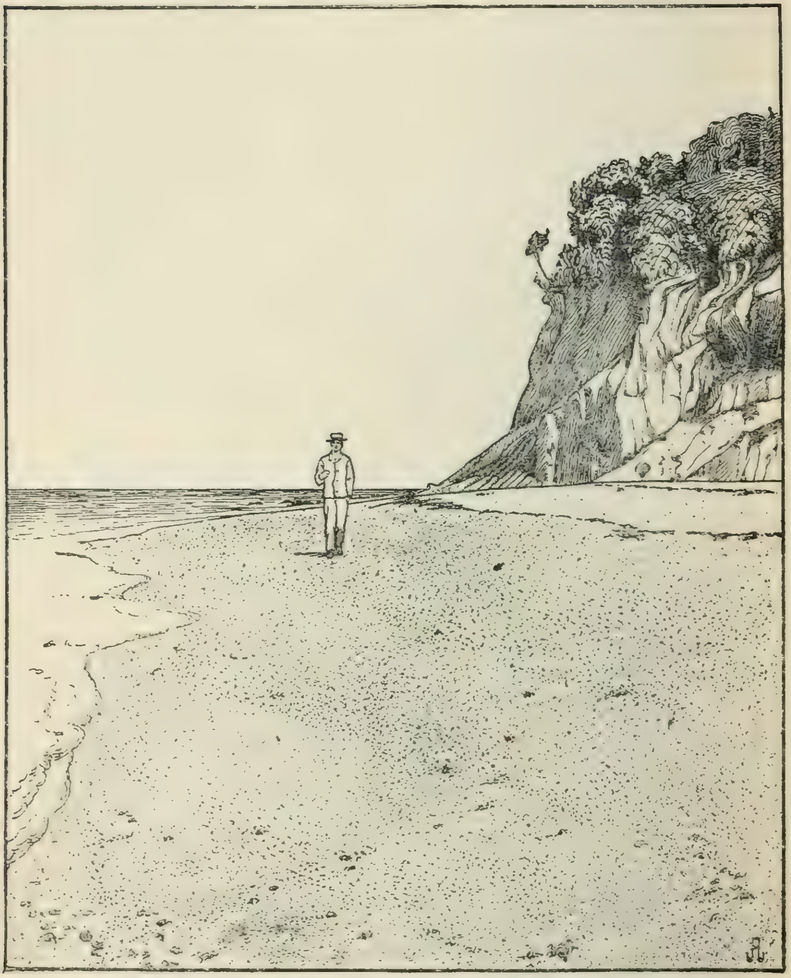

FIG. 4. The bluff at Cabo Branco seen from the beach.

A great many other instances have been observed along the coast of

Bahia, Alagôas, Pernambuco, Parahyba do Norte, and Rio Grande do Norte, but those already mentioned are enough to show beyond question that the coloring is an accident without any evident relation to the age of the beds.[1]

The Tertiary beds of the Amazonas. — Fossils supposed to be of Tertiary age have been described from the upper Amazon region, but the age of the beds referred to seems never to have been determined with certainty, though they are evidently not older than the Tertiary. As long ago as 1854 Foetterle spoke of the lignite beds of Iça, Tabatinga, Loreto, and Pebas on the Marañon, which he supposed were of Tertiary age.[2]

Orton found at Pebas near the southern boundary of Ecuador fossils which Gabb says "indicate a marine or perhaps rather a brackish water fauna. There is not sufficient material to warrant an opinion as to the geological age of the deposit," but he thinks they "point to a very recent era."[3]

Later Mr. Hauxwell made a larger collection at Pebas and at Pichua thirty miles below Pebas. This collection was described by Conrad, who is doubtful about the age of the beds.[4] He says that the fauna "may have lived in either fresh or brackish water, but it certainly is not of marine origin." The opinions of both Gabb and Conrad show that the statement of Orton to the effect that these shells "may be Miocene"[5] was premature. About the time that Conrad published his article there appeared one by Woodward upon a collection from the same region.[6] The author of that paper seems to take it for granted that Orton's opinion of the age of the beds was correct, and says nothing of any reason for referring them to the Tertiary.

In 1872 Hartt published an article upon the so-called Tertiary basin of the Marañon, but he never visited the region he was writing about, and based what he said upon the papers of Orton, Gabb, and Woodward, and on the notes of Steere.[1] Gabb's opinion of the age of the deposits he does not give correctly, but he quotes from Steere's notes facts that appear to strengthen the idea of the Tertiary age of the beds.

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[1] J. C. Branner. The oil-bearing shales of the coast of Brazil. Trans. Amer. Inst. Min. Engs., XXX., p. 537–554.

[2] Franz Foetterle. Die geologische Uebersichtskarte des mittleren Theiles von Süd Amerika. p. 20–21. Wien, 1854.

[3] W. M. Gabb. Descriptions of fossils from the clay deposits of the Upper Amazon. Amer. Journ. Conchology, 1868, IV., p. 197.

[4] T. A. Conrad. Description of new fossil shells of the Upper Amazon. Amer. Journ. Conchology, 1871, VI., p. 192.

[5] James Orton. The glacial deposits of the valley of the Amazons. Geol. Mag. 1870, VII., p. 540.

[6] H. W. Woodward. The Tertiary shells of the Amazons valley. Annals Magazine Natural History, ser. 4, Jan. and Feb., 1871, VII., p. 59–64, 101–109.

Dr. Oskar Boettger published in 1878 a paper upon the Pebas beds[2] in which he describes several new species of fossils. He says the fossils show the deposits to be of brackish-water origin laid down about the mouth of a large stream, that there are no marine forms whatever, and while he calls the beds early Tertiary he admits that inasmuch as the fauna of the region is unknown, the age of the beds is really doubtful (p. 503), — a view with which one must agree.

Dr. W. H. Dall writes me privately: "As regards the Pebas fossils, they are a unique and isolated group of which it is difficult to determine the age because all the characteristic forms are extinct and have no obvious relatives. It may be as old as Eocene or as new as Pliocene, but not, I think, younger."[3]

In 1879 Etheridge described a collection made by C. B. Brown from similar formations on the Solimões and Javarý.[4] These again are spoken of as Tertiary, but no reasons are given for this classification. Most of the species described by all these writers are new and the collections therefore have but little diagnostic value, especially in the absence of a knowledge of the existing fresh and brackish water faunas of that region.

Major Coutinho says that the formations at the mouth of the Huallaga in Peru and at the head waters of the Japura, the Juruá, and the Purús are the same as those of Marajó and along the coast to Piauhý.[5] From his description I take this formation to be what Hartt calls Tertiary and Agassiz calls glacial sediments. But this sweeping correlation by Coutinho must be regarded as extremely venturesome, and certainly without a sufficient basis of facts. The table-topped hills of the Amazon valley Hartt thought were Tertiary, but in these again no fossils were found.[6] Hartt says in speaking of these formations that his "opinion that they are newer than the Cretaceous and probably of Tertiary must be taken for what it is worth, until the question is settled by palaeontological evidence,"[1] and that is about all one can make of the matter. If we grant that the upper Amazon region from Iquitos to Tabatinga is Tertiary, there is no evidence that the mottled sediments of the lower Amazon are of the same age, to say nothing of correlating them with similar-looking beds on the coast of Rio Grande do Norte, Parahyba, Pernambuco, and Alagôas — 2500 miles away. This seems also to express Professor Derby's view of the subject.[2] They are too far from the region discussed in this paper, and too little is known of the intervening country, for us to be able to connect the two.

---

[1] C. F. Hartt. The Tertiary basin of the Marañon. Amer. Journ. Sci., July 1872, CIV., p. 53–58.

[2] Die Tertiärfauna von Pebas am oberen Marañon. Jahrb. d. K. K. Reichsanstalt, 1878, 28 Band, 3 Heft, p. 485–504.

[3] Private letter, April 26, 1901.

[4] R. Etheridge. Notes on the Mollusca . . . from the Tertiary deposits of Solimões and Javarý rivers, Brazil. Quar. Journ. Geol. Soc., 1879, XXXIV., p. 82–88.

[5] Bull. de la Soc. de Géographie. Paris, Oct. 1867, XIV., p. 321–334.

[6] C. F. Hartt. Recent explorations in the valley of the Amazonas. Ann. Rep. Amer. Geog. Soc. N. Y. 1870–71, p. 246.

The later Tertiary deposits. — It seems proper to accept the general trend of the evidence that some of the Brazilian coastal sediments are of Eocene Tertiary age. At about a dozen known localities between Victoria and Natal these Eocene or some of the older rocks have resting upon or against them a series of soft and generally dark-colored sediments that are probably of Pliocene age. These later sediments, whether Pliocene or not, throw important light upon the geographical and geologic history of the coast, and for that reason the notes made upon the exposures are here given. That more facts are not at hand is due to a great extent to the uncultivated and jungle-covered condition of the country. The forests are thick and practically impenetrable the year round. The few known exposures, it will be observed, are all on the seashore. It is reasonable to suppose that these same rocks occur pretty much all along the coast, but they are difficult to find even when one can get into the vicinity of them.

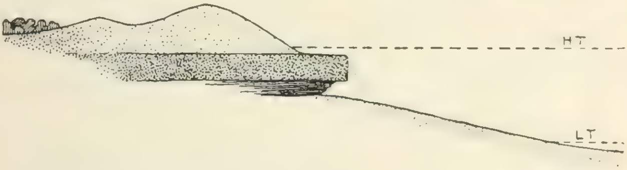

FIG. 5. Geologic section on the beach of the Cunhahú Valley.

Between Rio Cunhahú, S. lat. 6° 20′, and the bluffs at Bahia Formosa is exposed along the beach a dark brown or snuff-colored soft false-bedded sandstone. The lower part of these beds is washed by the tides, and the top of them, at a few places only, rises perhaps as much as a metre above high tide. Sand dunes lie on top of these beds, and behind the dunes the water soaks down, passes through the dunes, and following along the top of the rocks issues as amber-colored springs on the beach.

---

[1] Bulletin Buffalo Soc. Nat. Hist., Jan. 1874, I., p. 235.

[2] O. A. Derby. A contribution to the geology of the Lower Amazonas. Proc. Amer. Phil. Soc., 1879, XVIII., p. 176–177.

At one place a large spring has cut through the rock and comes out two metres or more below its surface. Not a trace of a fossil could be found in a kilometre of exposure of this rock. The beds are horizontal, but they do not appear in the Bahia Formosa section of the colored beds which are cut clear down to the water's edge. The snuff-colored beds must, therefore, rest unconformably against the valley originally cut by the Cunhahú in these sediments.

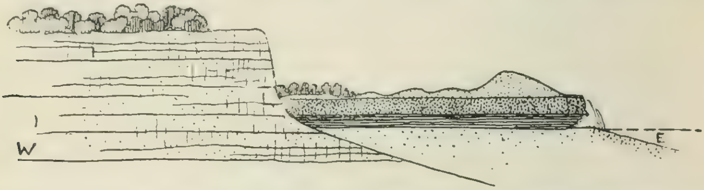

Fig. 6. Theoretic section showing the relations of the Bahia Formosa beds to the Cunhahú sandstone.

A few kilometres north of the Cunhahú and north of Rio Sibaúma, the bluffs have lying against them at one place horizontally bedded sediments made of fragments derived from these bluffs themselves.

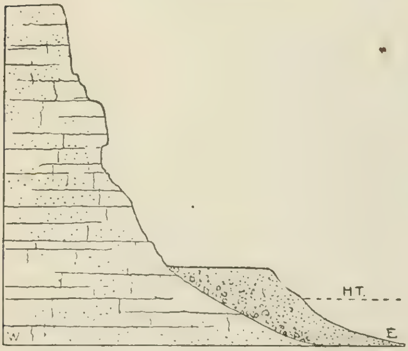

Fig. 7. Section through the bluff and beach north of Rio Sibaúma.

These beds contain no fossils, and from the appearance of the materials it is supposed that the newer beds here were deposited since the discoloration of the bluffs. At this place the top of the deposit is barely within reach of the highest spring tides. I am not at all sure that these newer beds are related to the snuff-colored ones.

At the mouth of Rio Mamanguape, S. lat. 6° 46′, on the point of land just east of the Barra de Mamanguape are exposed very dark sandstones, of about the same texture as the reef rocks and containing quartz, but in color from dark brown to perfectly black. Between the point and the village these rocks are strongly false-bedded, the false beds being a metre thick. These black beds extend under the village and appear at several places further up stream at low tide. The exposures about the point are all covered by water during high tides.

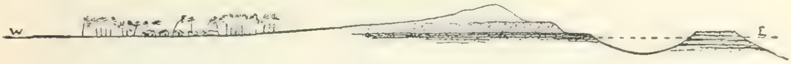

FIG. 8. Section showing the relations of the Mamanguape reef to the landward sandstones.

The top of these sandstones is about as high as the top of the stone reef outside, but it was impossible to make out the structural relations of the two. No fossils could be found in the dark beds.

At the village of Suápe, just south of Cape Santo Agostinho, a very black soft sandstone is exposed on the sandy beach at low tide. The exposure is only about ten metres long. The rock contains no fossils.

At the Barra de Serinhaem, S. lat. 8° 36′, these dark soft sandstones are exposed along the river bank at low tide for a distance of several hundred metres. No fossils were found in them. The church stands upon these beds which at this spot rise about two metres above high tide.

An important exposure of these rocks is uncovered on the shore between the village of Gamella and the mouth of Rio Formoso, S. lat. 8° 40′. Upstream on the north side of the river the Tertiary beds are well exposed in a vertical bluff at the end of the hill upon which the church stands. On the northeast side of this hill a low ridge strikes off toward Gamella and the encroachment of the sea upon this ridge has exposed its rocks well. The section is shown in the following sketch.

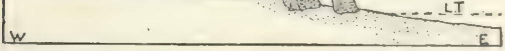

FIG. 9. Geology of the beach at Gamella, Rio Formoso.

The beds of this section below the thin seam of yellow clay are probably Eocene Tertiary, and are exposed in the bluffs south of the church, but the snuff-colored bed and the white sands are not in that section.

If the continuity of the two sets of beds could be seen, I should expect them to come together in some such manner as this:

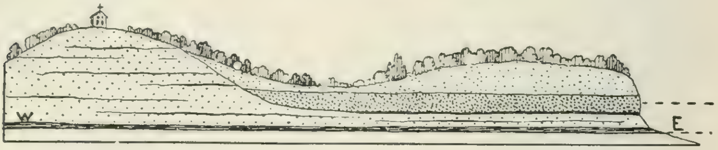

Fig. 10. Section showing the relation of Guadalupe Hill to the Gamella beach near Rio Formoso.

Unfortunately no fossils have been found in these rocks.

Three hundred metres upstream from the mouth of Rio Maragogý, S. lat. 9°, 3′, on the south side of the stream, there are fragments of a dark soft sandstone very like some of the beds here described, but these beds contain a few shells, especially *Venus*. In the absence of these shells I should have classed it with the snuff-colored beds; in the presence of them I took them to belong to the stone reef rocks, — a distinction that will perhaps give a good idea of the lack of data for the palaeontologic classification of these rocks.

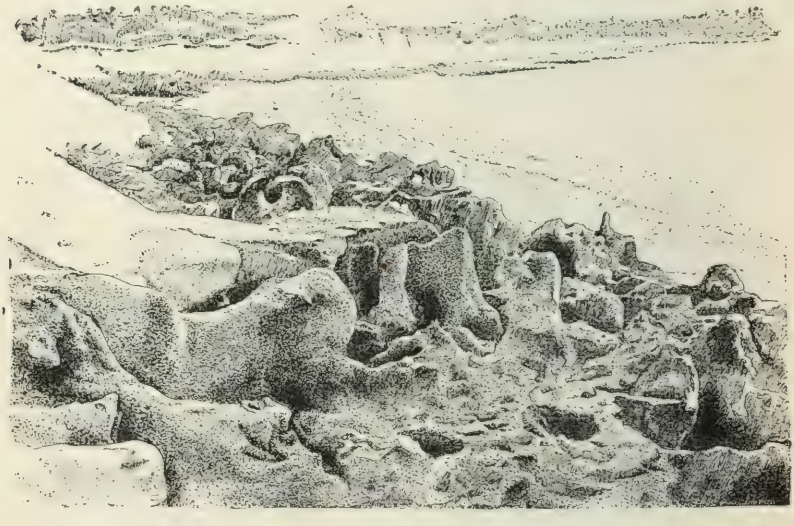

Fig. 11. Example of erosion on the beach, Gamella. From a photograph.

On the Rio Sergipe, nine kilometres west of the city of Aracajú, S. lat. about 10° 52′ 30″, beds similar to those above described are exposed on the east side of the river between Aracajú and Porto das Redes. The rocks are mostly soft, but here and there they are somewhat hardened.

Wherever the water comes from these snuff-colored beds it has a dark amber color.

Sandstones similar to these occur on the south end of the island of Itaparica, Bay of Bahia, just south of the village of Catú, and on the opposite side of the passage for a kilometre or two on the east coast of the island of Sant' Anna. These beds have not been examined. They are horizontal and rise two or three metres above high tide.

Near Caravellas the southeastern end of the Bahia e Minas Railway runs for nine kilometres over a recently elevated sea-bottom. West of kilometre 10 the line passes for five kilometres over the dark brown or snuff-colored soft sandstones. These rocks are exposed only in the bottom of the trenches beside the track. They lap over the Tertiary (?) red beds that extend from kilometre 19 to the western edge of the Serra dos Aymorés. Rocks of the same kind are used about the city of Caravellas, brought, it is said, from the inland parts of the tidal estuaries, but taken out at low tide always.

Attention should be directed to the section given at São Thomé in Chapter III. of this report. It will be seen that with the shell beds is one stratum that bears a strong resemblance to the snuff-colored beds found elsewhere. Whether this resemblance means anything I am not prepared to say. Ordinarily, of course, lithologic similarity cannot be used to correlate rocks, and least of all over such a wide area as that here under discussion. But if the São Thomé beds are to be correlated with the other soft sandstones of the coast, either the shell beds at that place are late Tertiary or the sandstones are more recent than the Tertiary.

As already stated, I am disposed to think that these late sediments that rest unconformably upon or against Eocene Tertiary or older rocks are of Pliocene age. If this supposition is correct, the Miocene period is represented on the coast of Brazil either entirely or in part by the erosion between the Eocene and the Pliocene, and the land stood considerably higher during Miocene times than it does at present.

Recent deposits. — In the absence of thoroughly trustworthy data by which the Pliocene beds can be discriminated from the older and newer sediments, it is evidently difficult to offer much regarding Pleistocene or recent deposits.

It has always been supposed that the shell beds about the Bay of Bahia were recent, and no good reason is known for saying that they are not. But no careful study has ever been made of the shells in these beds and of their relations to the living shells of the coast, and until such a study is made the age of the shell beds cannot be considered as determined. It has always been supposed, too, that the stone reefs of the coast were recent, but without a comprehensive study of their fossils and of the living fauna of the region it cannot be said positively whether they are recent or Pleistocene or some of them even of Pliocene age. For this question of the age of the later deposits along the coast is necessarily closely connected with the question of the ages of both the stone and coral reefs. If the stone reefs and raised beaches are late Tertiary, then the coral reefs are also Tertiary as well as recent, for the raised beaches at São Thomé, Porto Santo, and about Caravellas contain fragments of reef-building corals. In any case the later deposits along the coast are usually shut in the drowned river mouths and lakes, and in the old choked up embayments described in Chapter V. of this report. The stone reefs belong with these later deposits.

Conclusions regarding the geology of the coast. — The interiors of all the states along the coast between Espirito Santo and Rio Grande do Norte are of old crystalline rocks. Against these old rocks rests a strip of sedimentary beds that varies considerably in width, and is even entirely wanting at several points. At the base of the sedimentary series appear to be isolated Cretaceous basins (and possibly even older ones) overlapped by the more widespread Tertiary beds.

The sedimentary rocks of the Bahia basin hitherto regarded as Cretaceous appear to embrace more than one terrane. The oldest of these beds are Cretaceous (or possibly even Jurassic), and above these are probably Eocene beds, which are in turn overlain by later ones probably of Pliocene age. The separation of these several terranes cannot be made without more detailed stratigraphic work. South of Bahia as far as Abrolhos, and north of Bahia, at least as far as Natal, we seem to have here and there in the coastal sediments a stratigraphic problem very similar to that of the Bahia basin, but with less data with which to solve it: there may be two or more undefined terranes with Cretaceous below and Eocene Tertiary above, or, if there is but one terrane, we have in Brazil a faunal combination unlike any known in other parts of the world.

The brilliant colors of the coastal sediments have been produced by weathering; they affect beds of different ages and to varying depths, and cannot, therefore, be used to determine the ages of the rocks. At many places these beds are somewhat folded, but the weathering has so affected them as to give them the appearance, as seen from the ocean, of being horizontal.

At low elevations there are at many places a series of sediments newer than, and resting unconformably against, the eroded Eocene rocks. These beds have yielded no fossils, with the possible exception of certain ones near São Thomé on the Bay of Bahia. They are here tentatively referred to the Pliocene. The break between the Eocene and Pliocene is thus referred with doubt to the Miocene period. This would make the stone reefs of the coast of Brazil a part of the Pliocene, or possibly of Pleistocene and recent age. Doubts regarding the exact ages of the Tertiary and recent deposits can be removed only by a more careful search for fossils and a study of the fossils and of the living fauna of the coast.

The sequence of geologic events in the history of the coast since and including Cretaceous time was apparently as follows: —

Event.	Time.
1. The deposition of the Cretaceous sediments during a depression of the coast	Cretaceous.
2. Deposition of the Eocene Tertiary sediments in the ocean and in fresh water lakes near the coast	Eocene.
3. Elevation, and erosion of land surface	Miocene.
4. Depression and deposition of the Pliocene sediments	Pliocene.
5. Slight elevation of the coast; erosion	Pleistocene to Recent.
6. Slight depression of the coast	
7. Elevation amounting to about two metres	

III.

Detailed Descriptions of the Sandstone Reefs.

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The Ceará stone reef. — I have seen the Ceará reef, but have never made a personal examination of it. The following notes are taken from Sir John Hawkshaw,[1] who examined this port in 1875.

Ceará is in 3° 43′ south latitude, 38° 33′ west of Greenwich. Mucuripe Point spoken of is "about seven kilometres to the eastward." Mucuripe Point consists of sandstone rock, and is covered on shore with sand hills, but the low underlying rocks extend half a mile seaward at low water. "Mucuripe Point gives the roadstead of Ceará the appearance of a bay, . . . but the rocks project too little seaward and lie at too low a level to afford perfect shelter to the more distant anchorage at Ceará. There are more rocky shoals west of Mucuripe Point, with deep water between them, such as Meirelles reef, the Estrella Bank, the Velha reef, and the Corôa Grande shoal. . . . The Recife do Porto, a reef of sandstone stretching out in a diagonal direction from the shore at the east end of the town, is incorrectly shown on most of the charts. It gives some amount of protection at low water to lighters and small craft, but as the waves always wash over it except at low water equinoctial spring tides, this protection is very insufficient."

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[1] Melhoramento dos Portos do Brazil. Relatorio de Sir John Hawkshaw. p. 89–91. Rio de Janeiro, 1875.

He notes that a soft conglomerate is found in the bottom of the harbor behind the reef.

Borings were made on the reef showing the rock to be not much more than a metre thick. It is said that there was formed a channel between the reef and the shore.

The stone reef at Rio Grande do Norte. — The immediate shores about the mouth of the Rio Grande do Norte are covered far and wide with shifting sands. Southeast of the city these sands are being blown over the hills and into the river to such an extent as to threaten to destroy the navigability of the stream between the city of Natal and the bar. Behind these dunes mangrove swamps spread out across the mud flats that follow the river as far up as the tides are felt.

The topography of the region is beautifully seen from kilometre 3 of the Natal a Nova Cruz Railway. From this point one looks down upon a broad flat valley where water merges into mangrove swamp and swamp into flat dry lands, all ending abruptly against the sedimentary hills to the north. This flat country continues westward up the estuary of the Jundiahý to the town of Macahýba, everywhere the same as far as the general features are concerned.

In the city of Natal itself the same topographic relations are visible in the open square in front of the railway station.

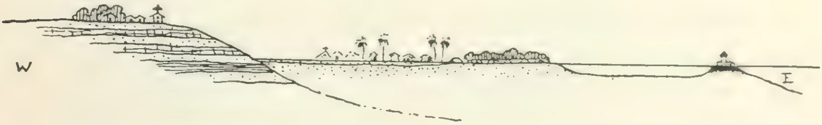


FIG. 12. Section from Natal to the Stone Reef.

It is worthy of note that the reef is on a level with the mangrove swamps, and but slightly below the level of the land upon which the lower city stands. The Tertiary hills on which the upper part of the city stands plunge as abruptly beneath the flat land at their base as if that land were a water surface.

The Natal or Rio Grande do Norte stone reef connects with the shore at its southern end, while its northern end stands squarely across the mouth of the Potenguí, or Rio Grande, so that the water of that stream flows round the north end of the reef to escape to the sea. The length of the reef from its northern end at the bar to where it joins the land is fifteen hundred metres; its length from where it joins the land to its southern extremity is three kilometres, making a total length of four and a half kilometres for the entire reef visible above water. North of the bar the surf breaks upon the concealed continuation of the reef in that direction. These breakers lie in the axis of the main reef.

The various breaks and topographic relations of the reef are shown on the accompanying map made by my assistant, Mr. C. E. Gilman, and need not be verbally described. It will be seen that this reef is nearly straight. In width it varies from twenty to seventy-five metres.

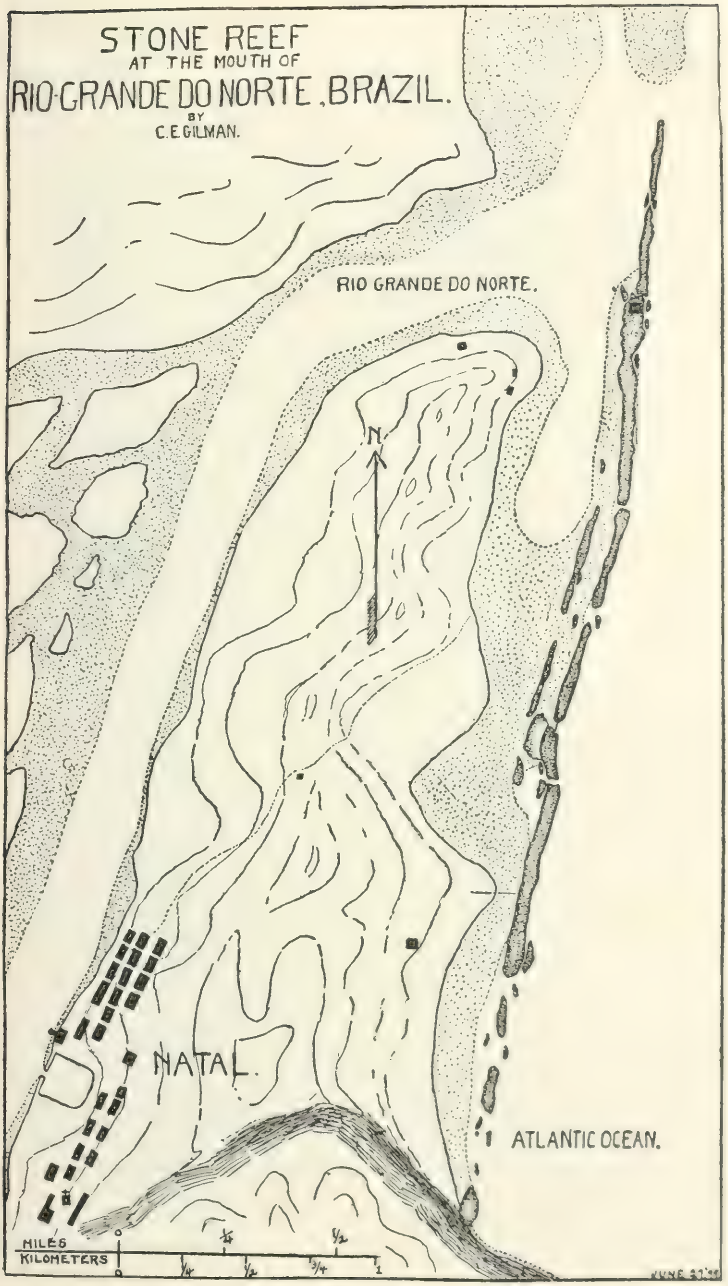
On that part of the reef that stands out from the land across the mouth of the river, and about six hundred metres south of the bar, is an old fortress now surmounted by a lighthouse.

Seen from a distance the surface appears almost perfectly flat. It slopes gently toward the sea, but the bedding of the reef rock has a somewhat steeper though still a gentle slope. In detail the surface is in some places flat, in others it is etched in a manner characteristic of all the sandstone reefs, and well illustrated in the photograph of the etched surface of the Mamanguape reef. This etching is caused by the removal of certain portions of the upper beds of the rock, and the leaving behind of other and more resisting parts which stand out upon the surface as sharp points or irregular slabs supported by short columns. These jagged points are usually from a few centimetres to three decimetres high, but sometimes they are a metre high and make it difficult to walk over the surface.

Where the reef is broken and the surface has fallen in so as to be lower than the general level, it is uncovered but little as compared with the higher parts, and here the surface of the fallen blocks is overgrown with barnacles and is black with seaweeds and corallines and is sometimes bored by sea-urchins.

Along the outer or seaward face the reef is more or less protected from the force of the waves by enormous slabs that have been dropped where they now lie by the undermining of the original reef by the sea. These slabs lie tipped about at various angles, but generally with their outer ends dipping abruptly beneath the sea, and thus forming an effective breakwater against the onslaught of the surf. Here and there the outer face is broken off abruptly. The entire seaward face of the reef is covered with corallines and other Algae, while the somewhat protected parts are furrowed and bored by sea-urchins. The cavities over this outer face of the reef and the seaweeds that grow there abound in the forms of marine life that generally inhabit such places.

The inner or landward face of the reef along its southern end lies against the land, or rather the sands of the shore come down upon and


STONE REEF
AT THE MOUTH OF
RIO-GRANDE DO NORTE, BRAZIL.
BY
C. E. GILMAN.
RIO GRANDE DO NORTE.
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NATAL.
ATLANTIC OCEAN.
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Fig. 13.

over its landward edge. In the main the relations of the shore sands to the reef are concealed. From where the reef leaves the shore and has water on both sides of it, the landward face in some places is broken off squarely, in others it slopes down gently in steps only a few centimetres high to low-water level.

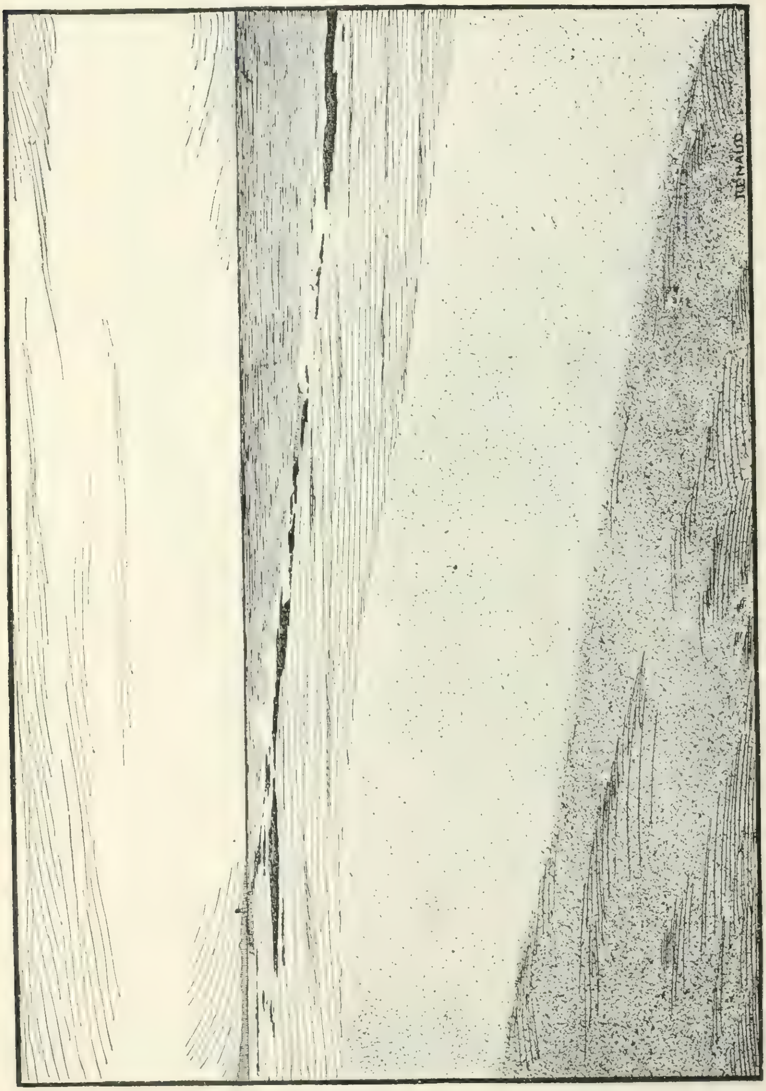


Fig. 14. Sandstone reef at Rio Grande do Norte seen from the south. From a photograph.

In contrast with the outer face there are but few big blocks along the inner face of the reef, and these are but slightly removed from their original positions. The depth of the water close to the reef along much of its inner face shows it to be a steep-faced wall, in places five metres or more in height.

To the landward of this main reef are to be seen here and there, especially at low water, portions of an inner, subordinate, and somewhat lower stone reef. This inner reef is approximately parallel with the outer one, in some places uniting with it, in others drawing away from it. The rock of this subordinate reef is the same as that of the larger reef, but as a rule not so hard. From a point fifty-five metres south of the fort this inner reef runs southward parallel with the outer one, and from eighty to ninety-five metres away from it, for a distance of a kilometre. As compared with the main reef, this one is rather narrow, being only from nine to thirty-five metres wide. Along this southern end the inner reef is so low that it is all covered by ordinary high tides.

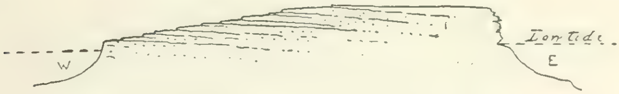


FIG. 15. Section across the stone reef, Natal.

At the fort the outer and inner reefs unite, and it is on the broad part formed by this junction that the fort is built. North of the fort again the two reefs no longer appear as one. The inner reef here apparently comes to an end, and the only remnant of it visible is on the northern side of the river and opposite the bar, where it forms a breaker uncovered at low tide.

Much of the surface of the whole reef is so covered with Algae, corallines, barnacles, and polyps that the nature of the rock is not apparent. In some places again the rock is bare, and large sand grains, pebbles, and shells may be seen protruding on the surface. Everywhere the freshly broken rock shows it to be a hard sandstone, so hard in fact that the quartz grains and pebbles often break squarely across, and the fresh fracture glistens very like that of a quartzite. Loose slabs and projecting points of the rock often ring under the hammer like clinkstone.

One of the most striking characteristics of this rock is the fresh appearance of the fossil shells it contains in abundance. These shells are apparently the same as those found living upon the adjacent beaches and sandbars.

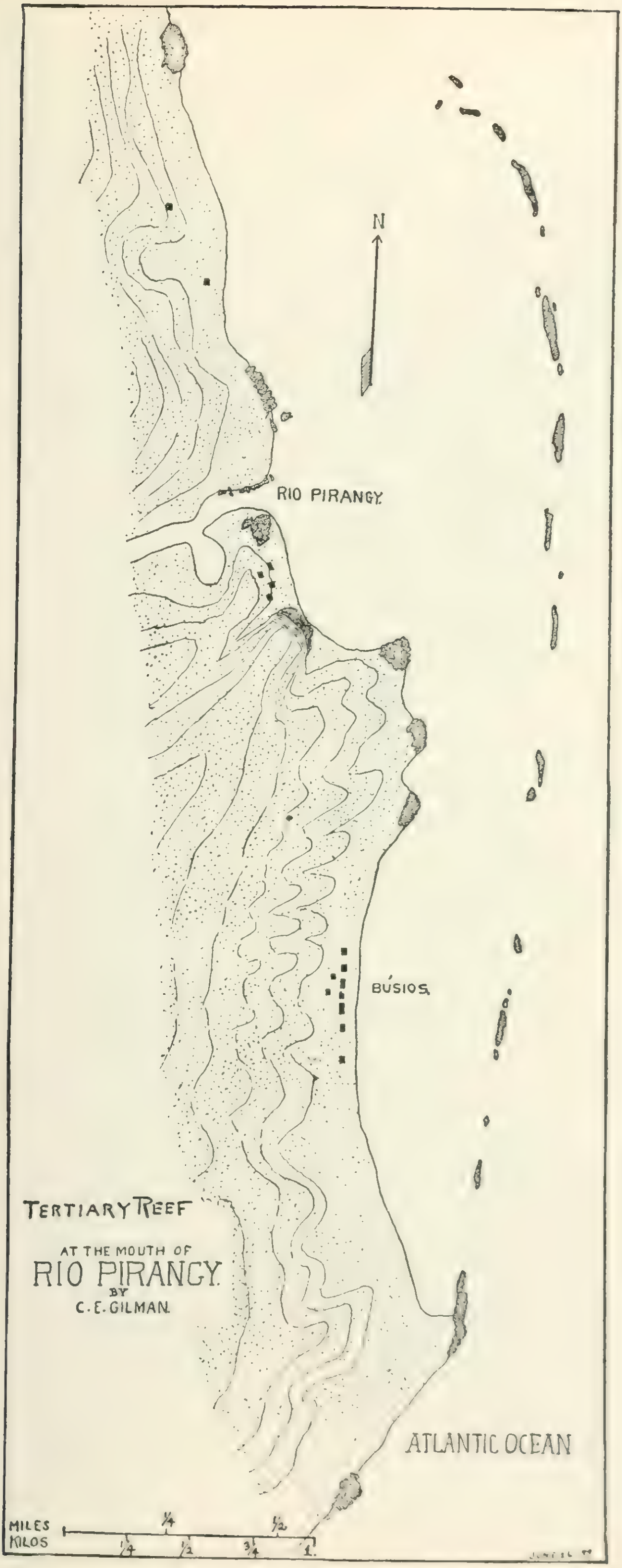
The Pirangý rock reef. — At Pirangý, south of Rio Grande do Norte, is the next reef that attracts attention. This reef does not, however, belong in the same category as the sandstone reefs of the Brazilian coast, neither is it a coral reef. It is mentioned here chiefly for the purpose of calling attention to a kind of reefs which are found occasionally on this coast and which are liable to be mistaken for either sandstone or coral reefs. The accompanying map shows the position and form of the Pirangý reef. It is, however, only the more resisting parts of the Tertiary (?) rocks that form the mainland in the vicinity.

The stone reefs of the Cunhahú and Sibaúma. — The Rio Cunhahú in the State of Rio Grande do Norte enters the ocean sixty-seven kilometres (in a line) south of the Natal lighthouse, and nine kilometres north of Cape Bacoparý. It descends through a wide-mouthed, flat-bottomed valley that extends from Bahia Formosa to the hills immediately north of the river, — a distance of seven kilometres. The hills south of the valley are put down on the hydrographic charts as being ninety metres high, and those on the north as being one hundred metres. A single isolated, round-topped hill stands out in the middle of this valley south of the river. It is shown in Plate **22** on the right.

This valley is a large and a long one, and retains these characteristics in the main for many kilometres, even above where it is crossed by the Natal and Nova Cruz Railway.

The immediate shores between Bahia Formosa and the mouth of the river are covered with sand dunes almost the entire distance. These dunes are at least fifteen metres high (a. t.), and on the west side their sands fall upon the sandy soil of a caatinga forest. On the oceanward side there are exposed beneath these dunes beds of snuff-colored to black false-bedded sandstones. These dark sandstones are in places from two to four metres thick, and lie unconformably against the red and mottled Tertiary (?) beds exposed at Bahia Formosa. The contact between these two series of rocks was not seen, but both sets of beds are horizontal, and the dark beds of a later age do not appear in the beautifully exposed Bahia Formosa section as they would do if they formed a part of it.

Here and there springs of amber-colored fresh water emerge beneath these dunes and upon the surface of the dark sandstones. At one place a large spring comes from the sandstone itself. In places the snuff-colored beds are below high-water level; in others they are somewhat higher. The geological relations of the beds are shown in the cut on page 28.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RIO PIRANGY
BÚSIOS
TERTIARY REEF
AT THE MOUTH OF
RIO PIRANGY
BY
C. E. GILMAN
ATLANTIC OCEAN
MILES
KILOS
1/4
1/2
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1.

FIG. 16. (See page 40.)

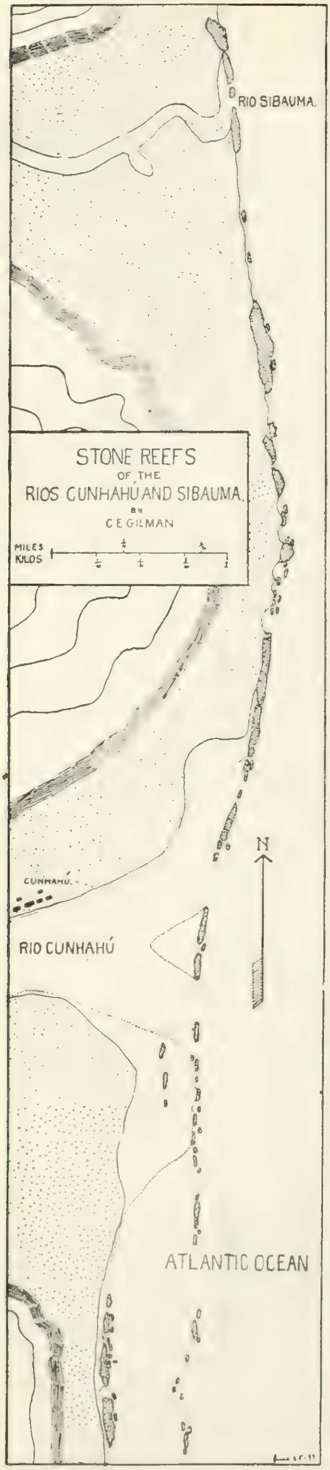

Fig. 17.

North of the Cunhahú there is only a narrow flat strip of land, barely wide enough for the houses of the village, between the river and the Tertiary (?) hills to the north.

Where the reef north of the river laps back upon the beach the Tertiary (?) hills are from one hundred and fifty to two hundred and fifty metres west of it; and this is as near as the reefs and the Tertiary (?) sediments appear to approach each other. North of this point the reef lies along the beach all the way to its northern end, while the Tertiary (?) hills draw off to the west and swing up the valley of the Sibaúma, and the belt of sand dunes widens across the mouth of the Sibaúma valley.

North of the Rio Sibaúma the sand dunes lie between the beach and the Tertiary (?) bluffs for half a kilometre, but here the colored beds are exposed on the beach, and the highest tides come within three metres of the base of the bluff. From this point northward the beach is close to and parallel with the Tertiary bluffs which continue to and beyond Moleque Point and Ponta do Pipa. These hills average about twenty metres high along their faces near the shore; inland they are higher.

The Cunhahú and Sibaúma reefs — originally one reef — have their southern end on the beach 2.7 kilometres south of the mouth of the Rio Cunhahú. This southernmost section is the inner reef of the two, and has a total length of eight hundred and seventy-five metres. It is nearly flat on top, but structurally it has a gentle seaward dip. The rock is rather soft, but otherwise it is like the ordinary reef rock.

This inner reef is, however, only a patchy one. The only other signs of it are immediately south of the mouth of the Cunhahú river, where several fragments are exposed at low tide.

The total length of the outer reef, including the Sibaúma end of it, and making no allowance for breaks and bars, is 8.4 kilometres. It is possible, however, that the whole of the northern end was not seen, as the tide was high when this part of the coast was reached.

The pieces that form the southern end of the reef were not inspected, but observations were confined to the portions accessible from the beach at low tide. These portions, however, form the great bulk of the reef. South of the bar the outer reef has so protected the embayment that the water is very shallow, and at low tide one can walk out to and beyond the fragments of the inner reef then exposed. The sand flats between the land and the reef contain many mollusks similar to those whose skeletons are found in the reef rocks.

Just north of the Cunhahú bar the reef is twenty metres wide. This portion of it gradually approaches the

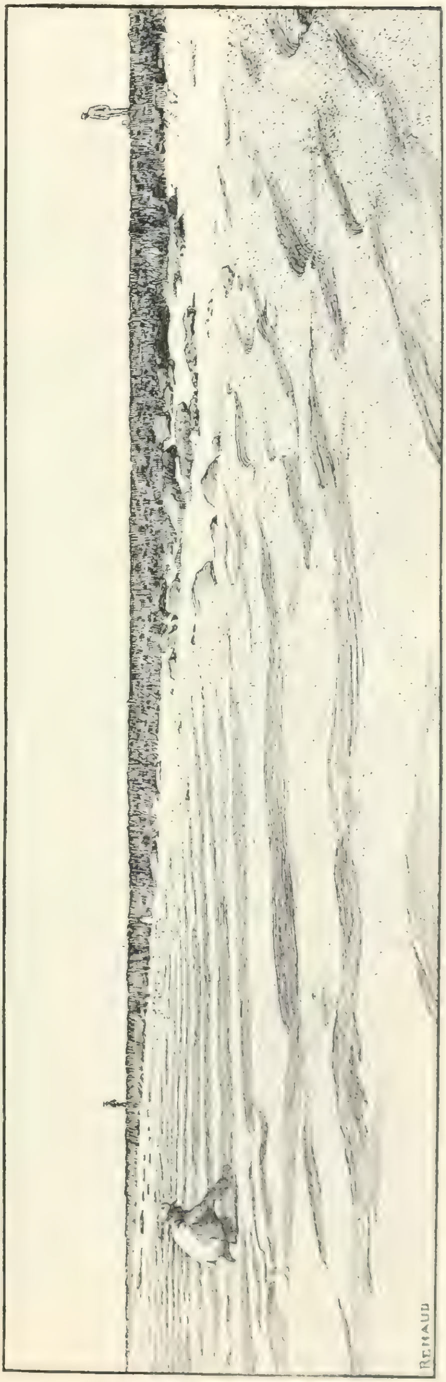

FIG. 18. Ripple-marked sands on the landward side of the Cunhahú sandstone reef. From photographs taken at low tide.

beach and finally merges into it. It appears to be perfectly straight; the slight curves of the entire reef are brought out only when one can get a view of it from some high point from which he can see lengthwise of it, or by a survey on a large scale.

The landward face of the reef is in places broken square off, but for the most part it slopes down rather abruptly but not at right angles. The outer face is in most places broken squarely off.

The top is flat, covered with small shallow pools, especially on the outside, and with low etched points studding the inner or landward margin.

The rock of the reef is like that of most of these northern stone reefs, — a light-brown sandstone of medium fineness, and varying slightly from place to place in hardness, coarseness, and the abundance of fossil shells. It contains many pebbles made of the red or black iron-stained sandstone so common in and characteristic of the Tertiary beds of the vicinity. It has also the usual fossil shells, though they are probably not so abundant as they are in some of the other reefs.

The sand-covered flat behind the reef is flooded at high tide; when the tide is out many big angular fragments of the reef rock are uncovered and left projecting from the sand. I did not see on top of this reef any loose blocks thrown up and left by the surf. The surf outside, however, is very severe at times, for there are no outside coral reefs to break the full force of the waves coming in from the deep ocean. I am disposed to think that the angular blocks partly buried in the sands behind the reef are pieces broken by the surf from the outer face and thrown completely across it.

A topographic peculiarity often seen in connection with the stone reefs that lie on or near the beach is well illustrated at several points along the northern end of the Cunhahú-Sibaúma reefs: where these inshore or beach reefs are broken clear through the sea is able to encroach upon the land, but only to a limited extent. The result is that semicircular bays of sizes proportional to the width of the openings are cut in these shores. A similar bay at Gaibú is illustrated at page 70.

The rocks of the southern end of the inner reef are covered with great quantities of a sandstone of organic origin, — a kind of rock I have seen only on this northern coast of Brazil. These rocks are formed by worms that cement together sand grains in masses resembling sandstone boulders. They appear always to be built upon hard rock bases.

The material is not hard where found on the beaches, but can be readily dug into with the sharp end of a geological hammer. Excellent examples cover much of the beach just north of Bahia Formosa, where the views reproduced in the plates were taken.

The examples mentioned as having been observed at the south end of the Cunhahú reef are the only ones seen upon a stone reef.

The Traição stone reef. — The Traição reef lies in front of the Bahia de Traição in the State of Parahyba. This and the Mamanguape reef to the south of it really form, or rather they appear once to have formed, one single and continuous reef, and to have been separated by the breaking down of what may now be called the southern end of the Traição reef.

The topographic features of the country back of the Traição reef are of rather more than usual interest, and what is said here upon this subject, in so far as it bears upon the origin, form, and history of this reef, is equally applicable to the Mamanguape reef.

To the west is a table-land of Tertiary sediments from twenty to forty metres high, of pretty even elevation and sky-line, but notched here and there by streams. This plateau, where it comes down to form the coast bluffs north of Traição, is shown in Plates **29 b** and **30**.

The sky-line at this place is noticeably less even than it is further south along this coast; the field notes on the locality remark that north of this place outlines of the coast hills have the appearance of sand having been blown over them. Where Plate **30** was taken the bluffs end abruptly as beach bluffs, and, swinging westward and northward with somewhat gentler slopes, pass along the east side of a long narrow marsh (for several kilometres, I was told), then return southward along the west side of this same marsh or lake and continue nearly due south until they approach near the Rio Mamanguape. Here the river makes a wide gap through these hills, but south of the stream they come to an end as inland hills at the Mirici red bluffs at the south end of the Mamanguape reef.

West of the village of Traição the church of São Miguel dos Milagres stands on the top and edge of this Tertiary plateau. Between the bluffs of São Miguel and the town of Traição the hydrographic chart shows a lake, known here as Lagôa de Sinimbú.[1] By courtesy it may pass as a lake, but strictly speaking it is little else than a fresh-water marsh with a sluggish stream flowing through it.

The Lagôa de Sinimbú is separated from the ocean by a low bank of sand which everywhere has the appearance of having been blown up from the beach. In places this sand ridge is scarcely high enough to keep the spring tides from flowing over it into the lake, but at one place south of the village it has a height of nine metres on the seaward side. From the village northward to the base of the hill on which the old fort stands this ridge is only from sixty to one hundred and twenty metres wide from fresh water to highest tide-level on the sea side. South of the village it widens out somewhat, and at one place is two hundred metres wide. The drainage of the lake is thus compelled to seek an outlet through the Rio Mamanguape, ten kilometres south of the low narrow neck north of Traição.

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[1] The name given on the chart may have been its name formerly, but it is now called Sinimbú.

Plate **30** shows this neck of sand with the bay to the right and the marsh of Lagôa de Sinimbú on the left.

A line of levels run across this neck shows that the lake water on July 24, 1899, was fifty-nine centimetres lower than the level pointed out as that of the highest spring tides on the sea beach. The mean tide-level, however, is a metre or more lower than the lake surface.

The Lagôa de Sinimbú and the flat lands about it and about the mouth of the Mamanguape lie as one broad flat region behind the reefs of Traição and Mamanguape alike. For a fuller discussion of these geographic features and their history and bearing upon the reefs the reader is referred to Chapter V., pp. 111 to 170.

The Traição end of the reef ends rather abruptly, standing boldly out to sea. At low tide one can walk dry-shod from Traição Point out on the stone reef, so that it may be said to join the land at that place. South of Traição Point the land draws away from the reef, forming thus the northern part of Mamanguape Bay, while north of the point the land swings away still more sharply to form the Bahia de Traição. A good view of the bay is had from the site of the old abandoned fort north of the town; from this point the photographs for Plates **29 a** and **29 b** were taken.

The Traição reef has a total length of only a little more than two kilometres; this does not include the fragments or outliers that connect this with the Mamanguape reef. Those fragments alone down to the bar have a total length of 2.4 kilometres.

A glance at the map shows that Traição reef has a gentle outward curve at Traição Point. It is rather broken, and its outer edge is ragged. In several places the waves are undermining it from the outside. On the whole it is a flat and rather smooth reef. Along the inner margin are the usual points left by surface etching, but they are not so high or so prominent a feature of this as of the Mamanguape reef. Over the surface are the customary tide-pools, though but few of them have any considerable depth. These pools lie mostly along lines parallel with the main axis of the reef. Much of the surface is covered with light green seaweeds.

The rock of the reef is a hard sandstone of a light brown color and contains many fossil shells.

The Traição reef, perhaps, more than any other one examined shows the effects of the wear and tear of the surf. Inside the reef there are many blocks buried in the sands, apparently broken from the outer face and thrown across by the waves; the outer edge is decidedly serrate, seldom presenting a bold face to the sea. Here and there the waves have opened beneath the reef great caverns in which they can be heard to swash back and forth. Sometimes these waves can be felt to jar the whole reef surface over an area of several hundred square metres.

For details of other characteristics of this reef reference is made to the description of that of the Mamanguape.

The Mamanguape stone reef. — The Mamanguape reef is one of the largest and most impressive of the stone reefs of Brazil. It is here described as a separate reef, but properly speaking it is continuous with the Traição reef to the north of it, and

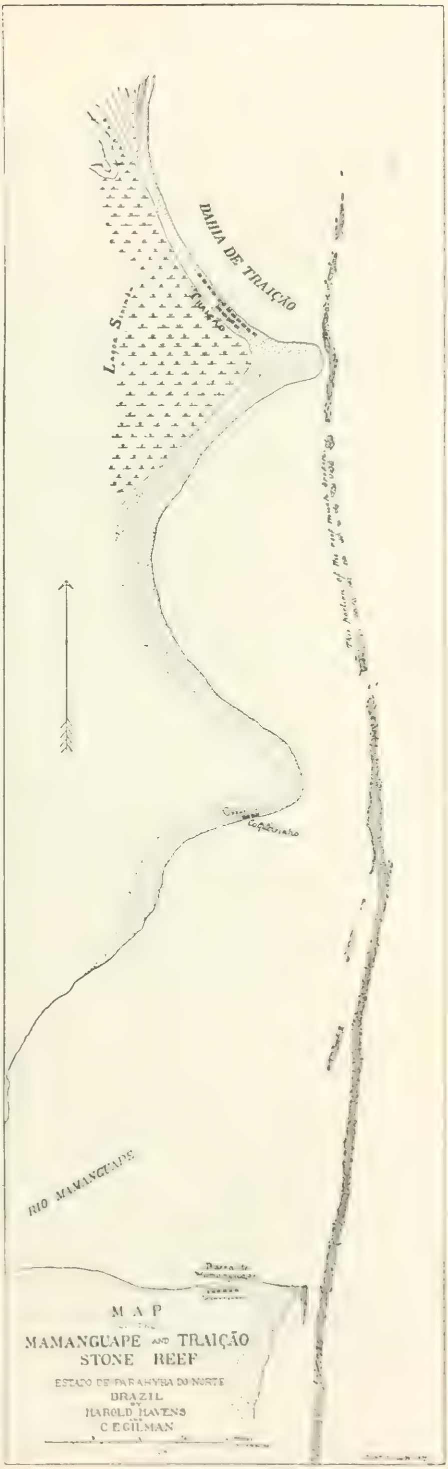
BAHIA DE TRAIÇÃO
Lagoa S
Traição
RIO MAMANGUAPE
MAP
MAMANGUAPE AND TRAIÇÃO
STONE REEF
ESTADO DE PARAHYBA DO NORTE
BRAZIL
BY
HAROLD HAVENS
AND
C E GILMAN

Fig. 19.

from which it is separated by only a few small breaks. At the south end also it continues far beyond the limits shown upon the accompanying map, so that, long as it is represented, its total length is not really known, and neither are its geologic and geographic relations about its southern end.

The Rio Mamanguape, a stream that drains a large area in Parahyba do Norte and in Rio Grande do Norte, flows down behind the reef and debouches both right and left through breaks or small bars, none of which lies in front of the river proper. The southern channel where it flows between the outer and inner reef is only about one hundred metres wide, but the channel is deep and the current is strong.

The country landward is all flat and low back several kilometres to the base of the hills or table-lands that skirt all this northern coast. The bay itself is mostly quite shallow, and at low tide looks like a series of sand banks and shallow ponds. In the deep water of this bay the dredge brought up only sand and fragments of broken shells.

The northern end of the reef that lies south of the Barra do Mamanguape is a single, flat, and nearly straight reef down to a point shown on the map, one and a half kilometres south of the bar, where it has the appearance of branching. Here a smaller and lower reef puts off from the main one and runs parallel with it and at a distance of about one hundred metres from it, until after several large breaks it joins the beach west of the river at Mamanguape Point. This inner reef is really a lower bed or beds of the main or outer reef. Where the two separate the inner one can be seen to dip gently beneath the great outer one. The junction of the two is fairly well shown in Plate **34**. It is noticeable that while the lower reef is comparatively strong at this junction, it weakens southward as it separates from the larger one. The rock of the inner reef is of the same kind as that of the outer, save that it is not so hard.

At high tide (flood tide, June 23, 1899) the big reef was only 0.45 to 0.61 metres out of water at some of its highest points, while the surf broke over all of it save where isolated loose blocks have been piled on top of it. At low tide it stands from 2.1 to 2.4 metres out of water.

Considered lengthwise, there is but little difference in the level of the top of the reef, — perhaps not as much as one metre in its entire length, breaks excepted. Here and there it has been undermined, and the surface rocks of harder stone have been let down in these gaps and are now covered with barnacles, seaweeds, and the like. These breaks are of various sizes, from those that one can walk across at low tide to those barely large enough for jangadas to pass through. The breaks are most abundant south of Mamanguape Point where the outflowing river strikes it. Several of the minor breaks, even at the lowest tides, have the water flowing through them between and beneath the loose blocks that fill them.

Strictly speaking, the reef as a whole is not straight, but neither is it very crooked. The bends in it are quite apparent when one sees the reef itself, but on a map of small scale they hardly appear. These curves are such as one may see on any approximately straight beach.

Considered in cross-section, the surface as seen from the bar has a gentle slope seaward. In most places the landward face is abrupt, and the channel of the Mamanguape River passes close up against the reef-wall. Toward the southern end, however, and especially where the inner face has been protected by the secondary reef, the profile comes down at a gentler angle or by a series of small steps or low terraces.

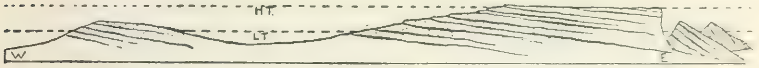

FIG. 20. Section across the Mamanguape stone reef.

The outer edge of the reef is here and there broken off with beautifully smooth vertical faces. But even in such cases it is protected to a great extent by its own fragments, many or most of which are gigantic blocks undermined on the seaward side and let down to where they now lie. To a notable extent these blocks lie at angles that make them most effective protective agents for the rest of the reef, and least liable to injury themselves from the onslaught of the sea. The following examples (Fig. 21) are types of the fractures observed on these faces.

In all these cases the sea is to the right and the reef to the left. It is noticeable in these instances that the broken fragments have the appearance of having been let down by undermining, and they now lie so as to serve as effective protection to the remainder of the reef, whether from undermining or surface wear. Many cases were observed, however, in which the fragments lie altogether at haphazard.

Some sheer faces more than three metres high are openly exposed to a tremendous surf apparently without being in the least affected by it. At one place there is such a face sixty-five metres in length. Now and then one may observe, when the surf is powerful, that the shock or jar of the blows is very marked over a given area. I take it that these places will eventually give way and form gaps or barretás in the reef.

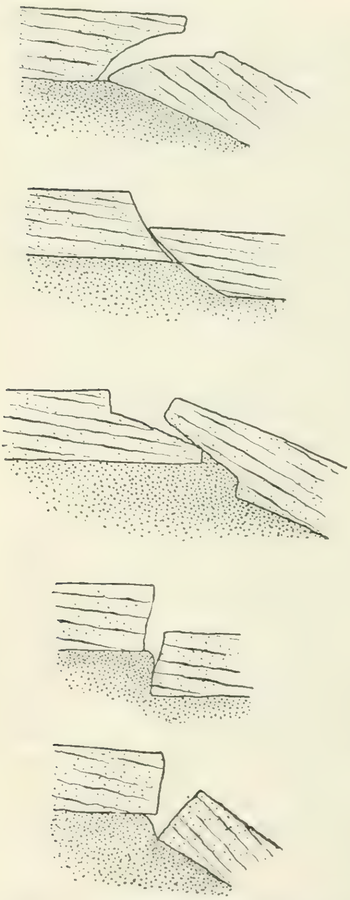

FIG. 21. Characteristic breaks of the outer edge of the Mamanguape stone reef.

That the surf has upon occasion been able to break off large blocks from the reef is shown by those now found lying loose on the surface at several places. One of these blocks is estimated (at one hundred and sixty pounds to the cubic foot — a low estimate) to weigh not less than nineteen tons. Another weighs five tons, and still another weighs twenty-two tons. This last one has been swept over and across the reef and now lies close to its inner edge. The five-ton block has its upper surface striated and polished very much as if it had been glaciated. This has been produced by its having been pushed gradually by repeated blows across the reef; when near the inner margin it was turned completely over and left where it now lies.

At another place north of the fork in the reef there are thirteen blocks or slabs, some of them weighing several tons, lying on top near the inner margin and within a distance of a hundred metres. Some of these pieces show by the position of the fossil shells they contain that they have been inverted by the waves.[1]

The rock of the reef is a slightly yellowish, rather coarse, but remarkably fresh-looking sandstone. In places it contains beds of pebbles, but these beds are neither thick nor wide-spread. Near the middle of the reef there is exposed on the surface a bed of quartz pebbles many of which are larger than one's fist. Mingled with the quartz are also, both here and elsewhere over the reef's surface, large pebbles of dark red Cretaceous or Tertiary sandstone such as occurs in the hills that skirt this coast. There are also occasional patches and lumps of a very black, compact, heavy rock made up of grains of titaniferous iron. At one place near Mamanguape Point a piece of this black iron rock, 4′ × 4′ × 5″, was found on top of the reef cemented compactly to an underlying bed of coarse white sand and pebbles. This rock is as black as coal, is composed of particles of black titaniferous iron sand, and shows false bedding. A few other blocks of similar material, one foot square, are near this one and attached in a similar fashion. Half a mile further south angular and subangular fragments of this rock the size of the two fists and some as big as one's head are buried in the sugar-brown rock of the reef, forming a sort of breccia for fifteen metres or more. At many other places this material occurs as pebbles scattered through the brown reef rock. These spots are caused by the concentration of titaniferous iron sands upon the ancient beaches. They are cemented by carbonate of lime and magnesia in the same manner as the other reef rock.

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[1] The majority of separated bivalve shells lie on a beach in such a position as to offer the least resistance to the water passing over them; that is, with the convex side upward.

The most characteristic thing about the rock of this and of all the other stone reefs is the presence in them of fossil shells of various mollusks now living along the coast. These shells are not evenly distributed through the rock, but are abundant in some layers and almost or quite wanting in others. Most abundant of all is a small, beautifully variegated, thick-shelled Venus known here as *mariscos*. These shells still retain in the rock their brilliant colors. The shells are never found in pairs as in life, but broken apart and with the horny cuticle they have when alive worn off. During their lives these *mariscos* burrow in the sand of sandbars and protected sandy beaches to a depth of about two inches. They are edible, and are used for food more or less all along the coast.

In one of the blocks near the northern fourth of this reef was found also a block of *Porites*, one of the hardy corals now growing upon the coral reefs and in the rocky tide-pools of the coast.

The reef rock proper when found in large slabs or projecting points rings under the hammer almost like bell-metal. It is, however, not everywhere equally hard: the upper beds, especially those exposed now and then to the sun and atmosphere, are as a rule hard and even quartzitic in fracture, while in other places the same beds may be rather soft and incoherent.

The surface features of the reef are not without interest. Here and there it is as flat and smooth as any sandstone slab for hundreds of metres; again it is so rough and uneven that it is almost impossible to walk over it. Over much of the surface there are shallow depressions that look like gigantic footprints made by mud-clogged feet in thick mud. At such places the surface of the reef has a profile like this:

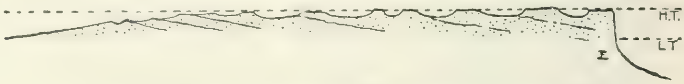

FIG. 22. Section across the Mamanguape stone reef.

In plan these pits have these and similar forms (Fig. 23):

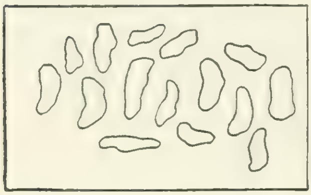

FIG. 23. Forms of the pits on surface of the Mamanguape reef.

These pits are from three to seven centimetres deep and from a few centimetres to two metres long. For the most part they are parallel, but sometimes they stand at various angles to each other.

The Mamanguape reef has some fine examples of etched surfaces. One of these is shown in Plate **41**, a photograph taken near the inner edge of the reef on its southern half. This etching leaves ragged sharp points that vary in height from a few centimetres to a metre, and a great number of fantastic forms.

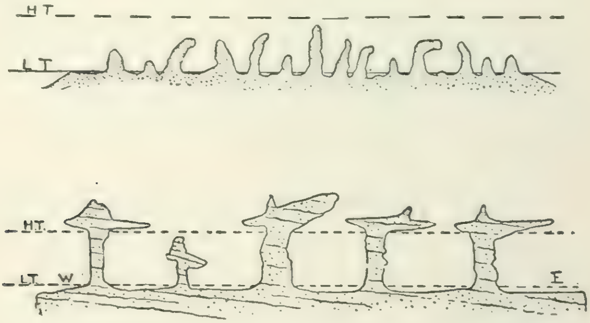

FIG. 24. Characteristic forms produced by the etching of the Mamanguape stone reef.

Some of the pillars on the Mamanguape reef are as much as two metres high; the tall ones are, as a rule, on the landward side of the reef, — never close to the surf-beaten sea side. These spike-like projections are invariably of very hard rock that rings under the hammer; they make walking over the surface of the reef in certain places almost impossible. Other points, rounded in outline, but standing at lower levels, are covered with barnacles.

There are but few places over the surface of the entire reef that have the rock freshly exposed. On the outer face and wherever kept constantly moistened with salt water, corallines and other Algae grow in greater or less abundance. Barnacles abound in the gaps and depressions in those places that do not receive the full force of the surf and yet are low enough or so situated as not to be long out of the water. Young barnacles speck the reef everywhere. The seaward edge, where the reef is flat, generally or always has a little low rim rising as a dam on its margin and enclosing shallow pools of water on top of the reef.

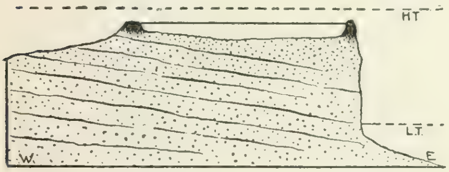

FIG. 25. Tide-pool formed by organisms on reef.

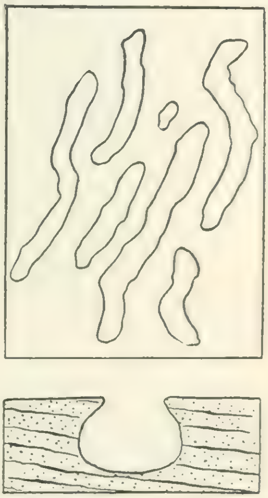

FIG. 26. Sea-urchin burrows on the surface of a sandstone reef; plan and section.

Oysters are found in patches along the inner face of the reef, especially where the ebbing tide brings the river water against it. There are occasional patches of dead oyster shells clinging to this inner part of the reef.

A large part of the outer surface and much of the top of the reef where it is kept constantly wet by the surf is full of holes and channels occupied by sea-urchins. These holes are two or three inches deep and of various lengths, from a few centimetres to two or three metres. They show a decided tendency to lie parallel to each other and with the direction of the waters that wash over them. In section they are undercut, as shown in the profile herewith.

These trenches are not full of sea-urchins, but have a few individuals scattered through them, or, at most, are half full.

Cracks are common over all the harder parts of the reef. These cracks run in all directions: some of them are parallel with the main axis of the reef, some are at right angles to it, many of them are forked, and some of them curve through an arc of ninety degrees within a distance of forty metres. These cracks are not open ones as a rule, though some of them are. Some of them gape broadly to a depth of four to six centimetres only.

These cracks look as if they were worn, but I have never been able to find any evidence of such wearing unless the form itself be accepted as evidence. At many places the crack has the rock on one side of it five or six centimetres higher than on the other, much as if the rock were slightly faulted. It should be added that they are not faults.

Some cracks that would otherwise be open at the surface are closed by the ingrowing of Serpulae. These cracks are generally deep, but are only seven centimetres or less in width.

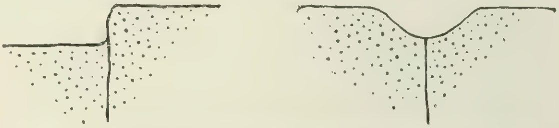

Fig. 27. **Sections across typical cracks in a stone reef.**

Almost everywhere that the rocks are weathered or unprotected they show false bedding, and less frequently they exhibit the true bedding. In Plate **41** the true bedding can be plainly seen.

The tide-pools over the surface of the reef contain fishes, crabs, and the like. Of the corals only a few forms are found in these pools: most abundant are *Porites* and the small heads of *Favia.*

There are no signs of a coral reef seaward of the Mamanguape sandstone reef.

It is unfortunate that I was unable to see the southern end of the Mamanguape reef and to learn something of its geologic relations there. It is also to be regretted that the bearing of what could be seen at the point where the reef approaches nearest the shore at Barra do Mamanguape is not altogether clear, except as it can be explained by reference to other places.

As shown on the accompanying map, the great outer reef continues southward past Mamanguape Point a kilometre or more, bearing south 6° west (magnetic) and parallel with the shore. Immediately west of the reef, and running against it as if against a wall, is the south-flowing mouth of the river here a hundred metres wide. West of this branch of the river is exposed at low tide a portion of the inner reef. This inner reef is here from ten to eighteen metres wide and three hundred metres long; at low tide it connects with and forms part of the beach. The rock is in places of a reddish color, and is not as hard as that of the outer reef. Fifty metres west of the inner reef and exposed on the river bank at low tide is a soft pebbly sandstone, in texture very like the reef rock, but containing no shells and varying in color from a dark brown to perfectly black. These black beds underlie Mamanguape Point and are barely covered at high tide. The Mamanguape Point itself is of white sand to a depth of eight or nine metres, heaped up here by the wind, but thinning and disappearing east of the village of Barra do Mamanguape. Beneath this sand the black rocks pass westward round the point and up the river to and beneath the village, above which it is still visible here and there. These black sandstones are about on a level with the outer reef. They appear to have been colored by organic matter. In places they are strongly false bedded. (Compare geology of Rio Formoso.)

The consolidated beaches of Parahyba do Norte. — At the entrance to the Rio Parahyba do Norte, State of Parahyba do Norte, the great reef on which the lighthouse stands is of coral. This will be described in the second part of the present paper.

Properly speaking, there is no sandstone reef in the vicinity of this port. The coral reef is only about one kilometre from the shore, with which it is parallel. From the Ponta da Matta southward for something more than a mile the beach is low, flat, and sandy, and planted with coco palms. Beyond this to the south begin to appear evidences of an old consolidated sand beach, and these signs continue for nearly twelve hundred metres. The beach, however, continues to be sandy, and the peninsula west of it is still low and flat. Loose blocks of the sandstone of the consolidated beach are sparsely scattered over the beach in some places, and in others the bed is exposed in place. The exposures are all between high and low water marks, and so far as was seen, are confined to the beach, where they are generally overlain by a metre or more of sand and soil.

The peninsula lying between Rio Parahyba and the ocean is narrowest one kilometre south of Fortaleza da Barra, and at or very near this narrowest part the remains of a consolidated beach are uncovered. This exposure is between the village of Cabedello and the beginning of the mangrove swamp on the right side of the river, and is nearer the swamp. The exposure is between high and low tides, the rock not very hard, and is composed largely of the sand of calcareous seaweeds of the same species as those now living on the coral reef outside the barra. The exposure of recent sandstone here is only about two hundred metres in length, and the locality is a little to the north of opposite the most northern exposure of consolidated beach on the ocean side of this neck of land, which is here seven hundred and seventy metres in width. The peninsula is all low, flat and sandy or swampy, and there are no hills on the south side of the Rio Parahyba do Norte until near the city of Parahyba about seventeen kilometres up the river.

Something will be said of the physical features of the region about the mouth of the Rio Parahyba do Norte in the part of this paper treating of the elevation and depression of the coast.

The Pedra de Galé or Goyanna stone reef. — The Goyanna stone reef or reefs lie off the mouth of Rio Goyanna, State of Pernambuco, one part of it being north and the other south of the Barra de Goyanna. Only the northern part of this reef was examined.

This northern reef is known to the sailors of the coast and to the people of the region as the *Pèdra de Galé* or *Recife de Galé*.[1]

The country to the west is hilly (Tertiary) both north and south of Rio Goyanna, and the river enters the sea through a flat region. The outstanding point between the hills is a low sandy flat planted with coco palms, but further west mangrove swamps stretch across the valley. The water landward of the reef is mostly shallow. The dredge brought up here only sand with a few shell fragments.

The reef is only a short one, is quite isolated, stands well out from the shore, and ends abruptly without any sign of a submerged continuation so common with the stone reefs. It is only a few hundred metres long, and varies in width from 15 to 25 metres. The surface is flat in the main, but has a gentle seaward slope. The rock is very hard and can be readily broken only on the projecting points left by etching. The surface is pitted unevenly, but the stone is nowhere bare. In places the rock is cracked, and great blocks, ten or fifteen metres across, have dropped a little as if undermined and let down in place right in the body of the reef.

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[1] These reefs are not properly located on the hydrographic chart of this coast. The northern one is there represented as lying nine miles north of the bar: by measurement it is about a third of a mile. The southern reef is represented as being seven miles long. That piece I did not measure, but as we saw it from our *barcaça* with the chart before us it did not seem to be nearly so long, even with all the outlying fragments included. The direction of the axis of the reef with reference to the land is also incorrect: the entire northern reef is in line with the low flat land one quarter of a mile west of Ponta de Pedras. Its magnetic bearing is north 27° east. (June 17, 1899.)

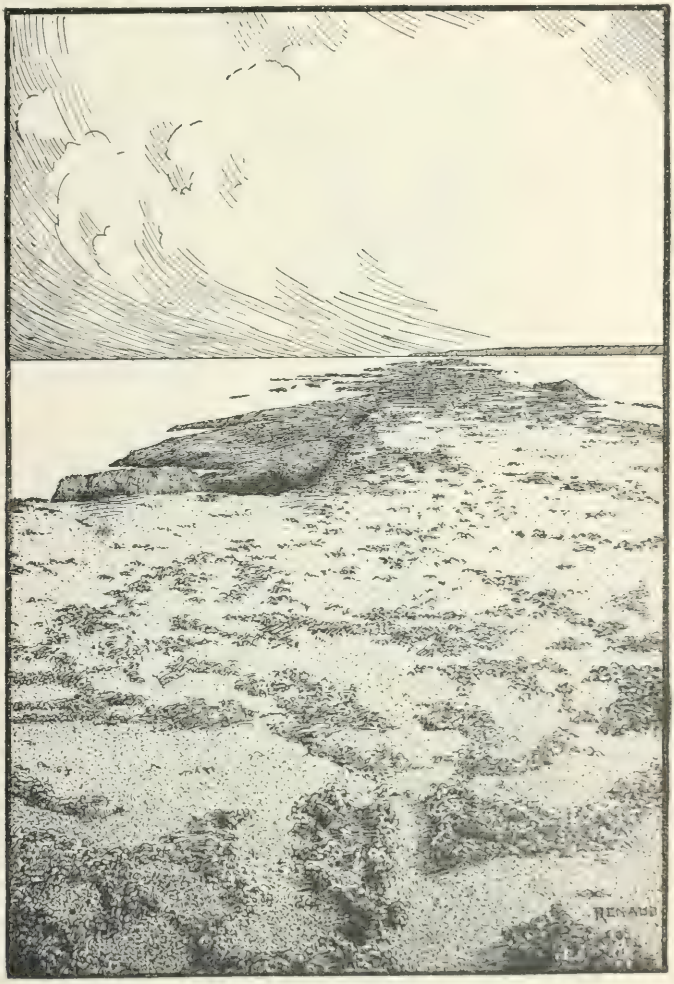

FIG. 28. Pedra de Galé reef. From a photograph taken at low tide.

Both on the outside or seaward face and on the inside square-faced blocks have broken off and been let down at various angles.

Barnacles cover much of the surface. In the surface tide-pools *Porites*

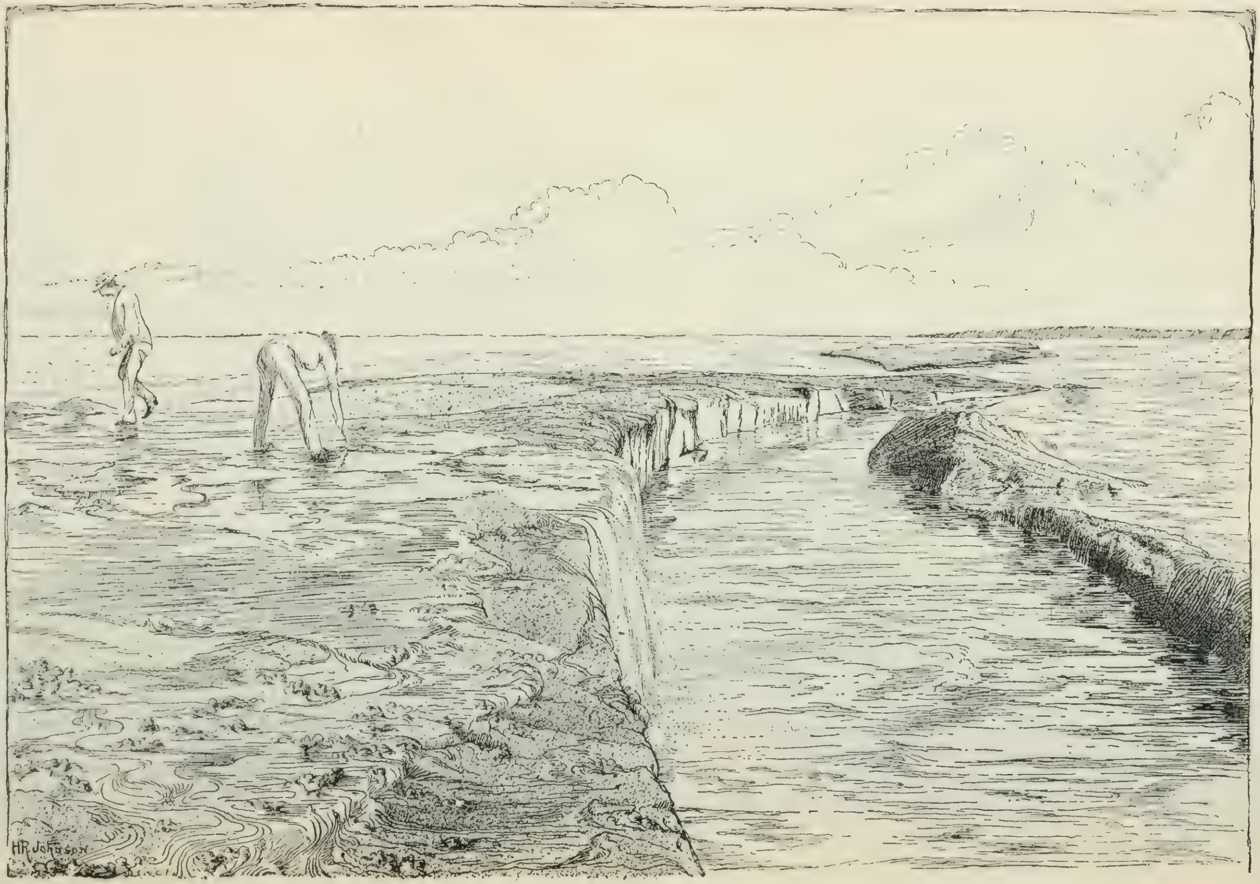

Fig. 29. Pedra de Galé sandstone reef. From a photograph taken at half-tide.

and *Favia* grow sparingly, and crabs, sea-urchins, and small fishes are abundant. The quieter waters on the landward side of the reef contain great patches of brown polyps and some small heads of *Porites*. The outer or seaward side of the reef is covered with polyps, corallines and other Algae.

The Rio Doce stone reef.—The Rio Doce is a small stream entering the sea 7.4 kilometres north of the Olinda lighthouse. From Olinda northward the Tertiary hills swing inland, and, keeping more or less parallel with the coast, approach the sea again only on the north side of Rio Maria Farinha.[1]

From one of the valleys cut across this Tertiary plateau and across the intervening flat country flows the Rio Doce. Along the beach both north and south of the river's mouth is a long narrow bank of loose sand from two to four metres high. Behind this bank the land is lower and flat, while near the river it is covered with mangrove swamps.

Beginning one kilometre south of the mouth of this river is a

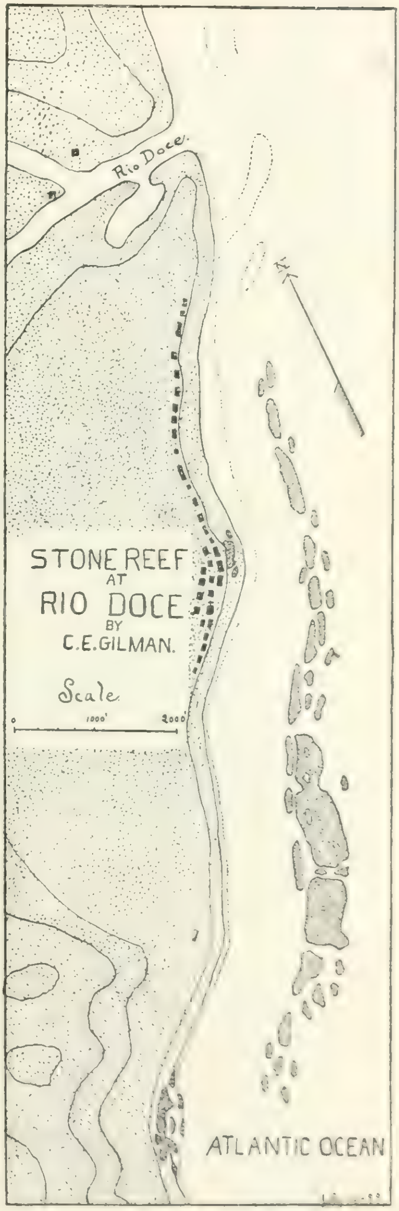

FIG. 30.

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[1] The hydrographic chart is at fault here in not showing the hills at Maria Farinha just north of the river. Besides, there are no such railways as those shown on chart 1503 running from Goyanna nearly to Olinda.

stone reef[1] extending southward along, partly upon, and partly off the beach, and having a total length of 3.3 kilometres. This includes also the fragments on the beach at its southern end. As will be seen from the map, the reef is more or less broken throughout, the longest piece being only fifty-three metres long.

It is fifteen metres wide at its widest part above water, but it dips gently seaward, and its total width is considerably more than this. It is Mr. Gilman's opinion that the largest pieces have a width to the east of about one hundred metres more than is shown upon the map.

The entire surface of this reef is thickly covered with corallines and barnacles.

At the southernmost point on the beach is an exposure of rock similar to that of the reef, and like it containing many shells and some pebbles, and strongly false bedded. These beach fragments are much etched.

At another place in front of the village and about half a kilometre south of the northern end of the reef is a similar exposure of sandstone on the beach three decimetres above tide, and underlying the sandy soil.

On the beach of calcareous sands are many bivalve shells, and similar shells are imbedded in the rocks of the stone reef.

The Pernambuco[2] *stone reef.* — The Pernambuco reef lies in front of a

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[1] The notes on the Rio Doce reef were kindly made for me by my assistant, Mr. C. E. Gilman. I have myself seen this reef several times, but many years ago, and my early notes on it have been lost.

[2] The name Pernambuco is variously spelled by the old writers on Brazil: Fernambouc, Fernambuquo, Paranambuquo, Pernambuck, etc. Hans Staden spells it "Prannenbucke." Fernandez Gama explains the name thus: "The native Indians called the bar *Pera Nambuco,* that is to say, broken rock or hole, in allusion to the opening through which the ships enter. . . ." (Memorias Historicas da Provincia de Pernambuco, Por José Bernardo Fernandez Gama, 1844, I., p. 97.) Macedo gives the same explanation except that he says the native words are *Pera-nabuco* (Noções de Corographia do Brazil, por Joaquim Manoel de Macedo, p. 101. Rio de Janeiro, 1873.) Sir Richard Burton says the etymology is *Paraná mbok or mbo,* meaning sea-arm. (Hans Stade of Hesse. Hakluyt Soc., 1874, p. 20.)

The fantastic explanations given by Johan Nieuhof, by Arnoldus Montanus, and by Rolt are quite out of the question. The first derives it from *Inferno enbokko,* which he understands to mean the mouth of hell, and to refer to the harbor mouth. (Gedenkweerdige Brasiliaense Zee-en Lant Reize. Amsterdam, 1682, p. 13.) Montanus says the word means "mouth of hell." Rolt accepts a similar explanation from the Portuguese *Infernoboco.* (A new and accurate history of South America. By Mr. Rolt. London, 1756, p. 546.)

For the correct explanation of the word see note under "Rolt" on pages 221 and 222 of this report.

Recife is the name of the older part of the city lying east of the Capibaribe. This word is simply the Portuguese for "reef," and is originally from the Arabic, — not from the Latin *recipere,* as stated by Barlæus. (p. 66.)

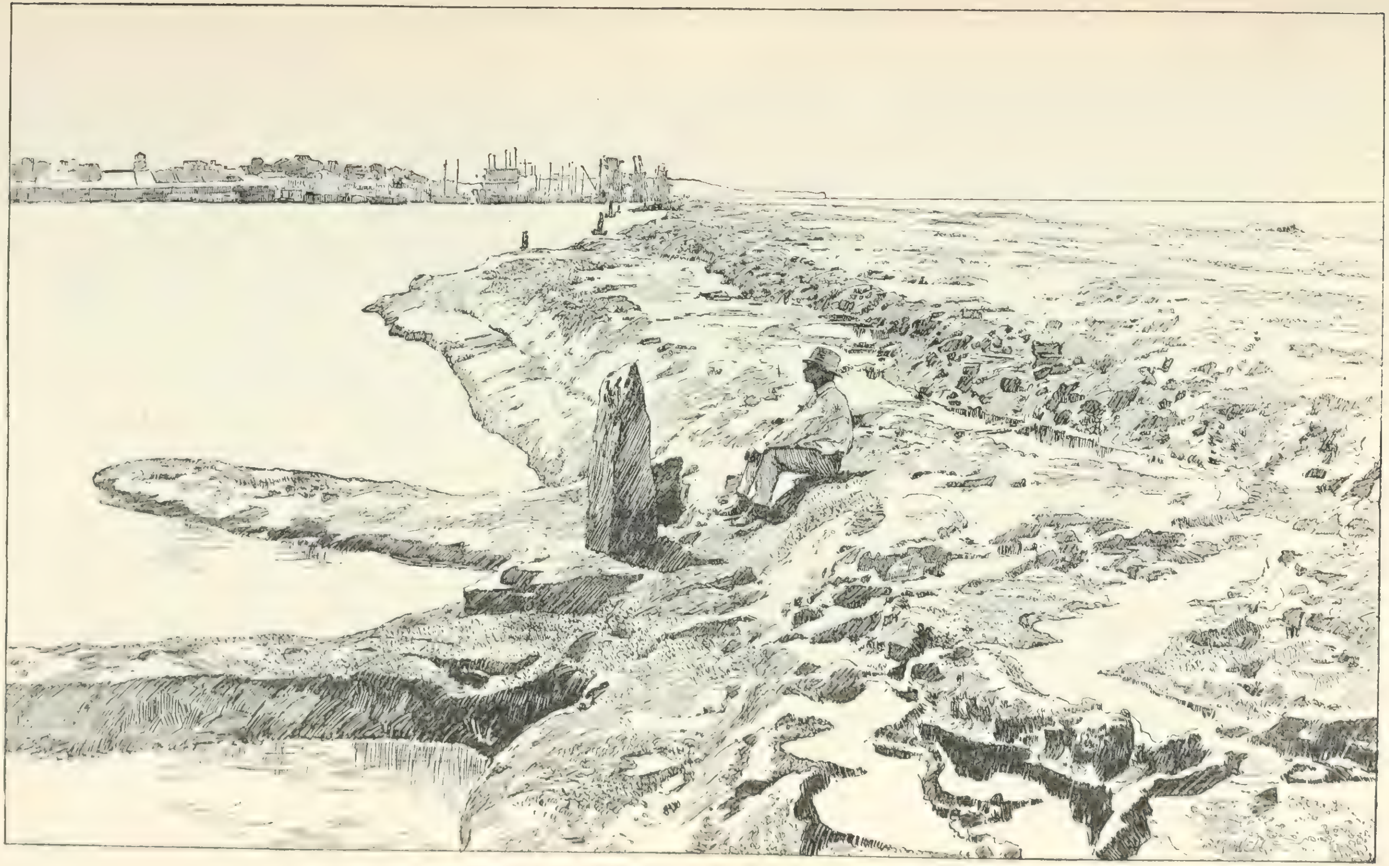

Fig. 31. Pernambuco reef, from a photograph taken near the south end.

low flat country. At Olinda, about five kilometres north of the city of Recife, the high lands reach the sea. The high hills swing inland from this place to Caxanga and approach the coast again near the town of Cabo, north of Cape Santo Agostinho. The flat country west of Pernambuco is a recent deposit, and a comparison of maps made during the Dutch occupancy during the first half of the seventeenth century (1630–1644) with the present features shows that the filling up of the old marshes and estuaries is still going on. Two streams, the Beberibe and the Capibaribe, flow across these low lands and enter the sea in the rear of the stone reef. These streams are not large enough for navigation except by canoes and other small boats. The tide ascends the Capibaribe twelve kilometres. From the high land at Olinda a sand spit extends southward, forming the shore and separating the ocean and Rio Beberibe for a distance of four and a half kilometres, to the mouth of the Capibaribe. The city of Recife stands on the southern end of this spit.

The channel between the Recife spit and the sandstone reef is two hundred metres wide in its narrowest part, while further south it branches to a width of nearly one kilometre. The narrow channel between the lighthouse and the mouth of the Capibaribe is deepest and forms the harbor of Pernambuco. In the broader portions the channel is considerably shallower. Five kilometres south of the lighthouse that stands on the north end of the reef the mainland at the Ilha do Nogueira is only three hundred metres from the reef. The reef from its northern to its southern end, a distance of six kilometres, is very nearly straight, and is unbroken save at one point, the barreta, where there is an opening wide enough to permit the passage of jangadas and such small crafts. At the north end of the reef it seems to be continued in the same direction by a submerged reef about six hundred metres long. Beyond this its course is not distinctly traceable by shoals. At the southern end the reef breaks down gradually, and its southward extension is only suggested by a few submerged isolated breakers lying in the axis of the main reef. There is no apparent difference between the appearance of the reef to-day and its appearance during the Dutch occupancy, as shown by the old prints made in 1645.

Seen from the sea the reef looks like a long, low, artificial breakwater of even surface and with a straight but ragged outer margin. This outer surface is overgrown with corallines and other seaweeds, Serpulae, polyps, barnacles, etc., and is also bored into by sea-urchins. At low tide it is exposed its whole length like a low black wall.

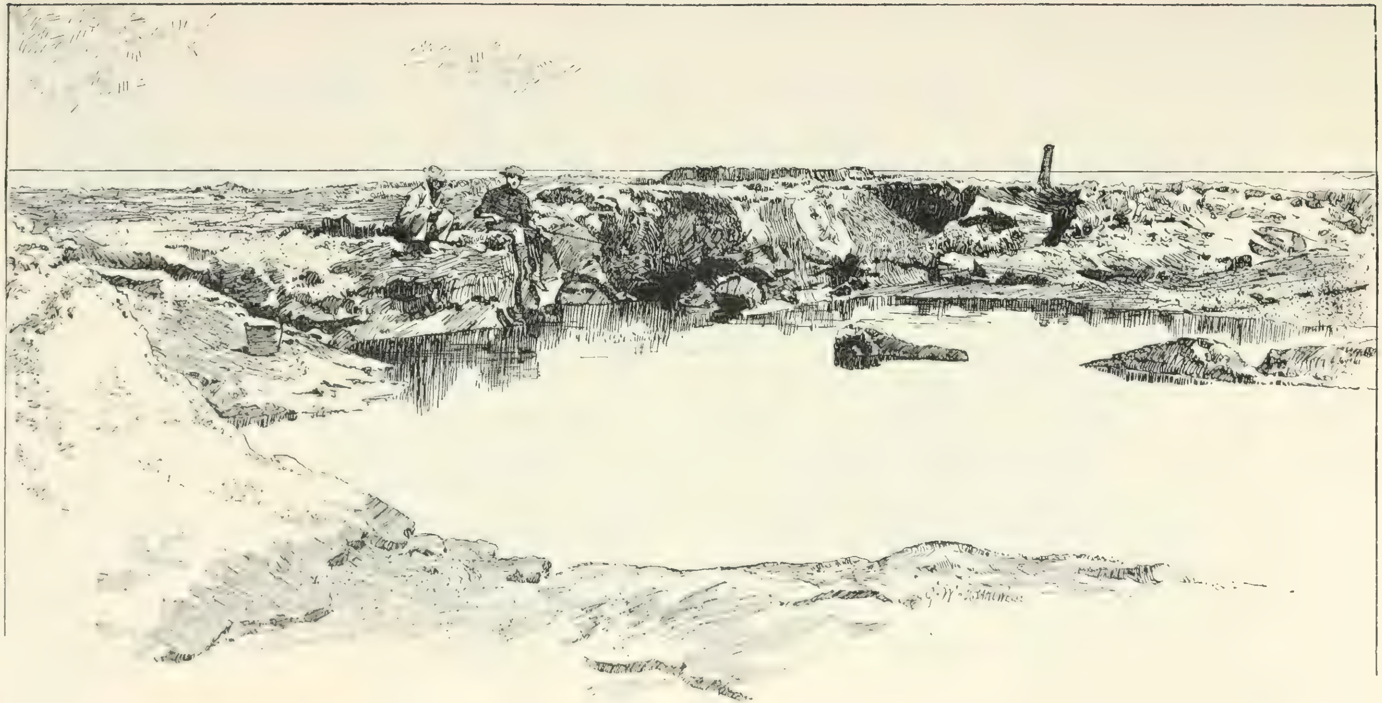

FIG. 32. The inner face of the Pernambuco reef. From a photograph taken at low tide.

At extreme high tide when the wind is high (neap tide at Pernambuco is less than one metre; spring is 2.2 metres), the surf breaks over the top of the reef almost its entire length, though not with force enough to disturb the shipping anchored in the narrow harbor behind the reef.

The upper surface is approximately flat, but somewhat rough, owing to the varying hardness of the rock and its uneven wearing. To protect the reef, and to prevent the surf from disturbing the shipping inside the harbor, an artificial stone wall was built during the Dutch occupancy along the northern end of it.[1] In width it varies from twenty to sixty metres.

The inner or landward face of the reef is slightly irregular, as is shown in the accompanying illustrations. The scour of the ebbing tides sweeps out seawards the silts brought down from the land, so that the inner face of the reef is abrupt, and the water close alongside is usually deep.

The reef rock is composed mostly of siliceous sand grains cemented by carbonate of lime. It contains besides many shells of such mollusks as live in the sea along the coast, and more or less calcareous matter from broken Serpulae tubes, mollusks, gorgonias, and the like. The shells retain their original bright colors.

The structure of the stone reefs was never certainly known until 1874, when Sir John Hawkshaw, the English engineer employed by the Brazilian government to report upon the harbors of that country, made a series of borings upon the Pernambuco reef and in the spit upon which Recife stands. These borings show that the hard rock is only three or four metres thick, and that beneath this are beds of sands, clays, marls, and shells. The deepest boring on the reef was made nearly opposite the landing-place at Recife, and was seventeen metres in depth. The record is as follows: —

RECORD OF BORING ON THE PERNAMBUCO REEFS.

	METRES.
Reef rock, hard	2.95
White sand	1.22
Shells	1.10
Gray sand	0.65
Broken rock	1.22
Dark sand	2.10
Mottled clay	1.80
Yellow clay	0.70
Gray sand	3.00
White sand	2.20

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[1] Journal of a voyage to Brazil, by Maria Graham, London, 1824, p. 101.

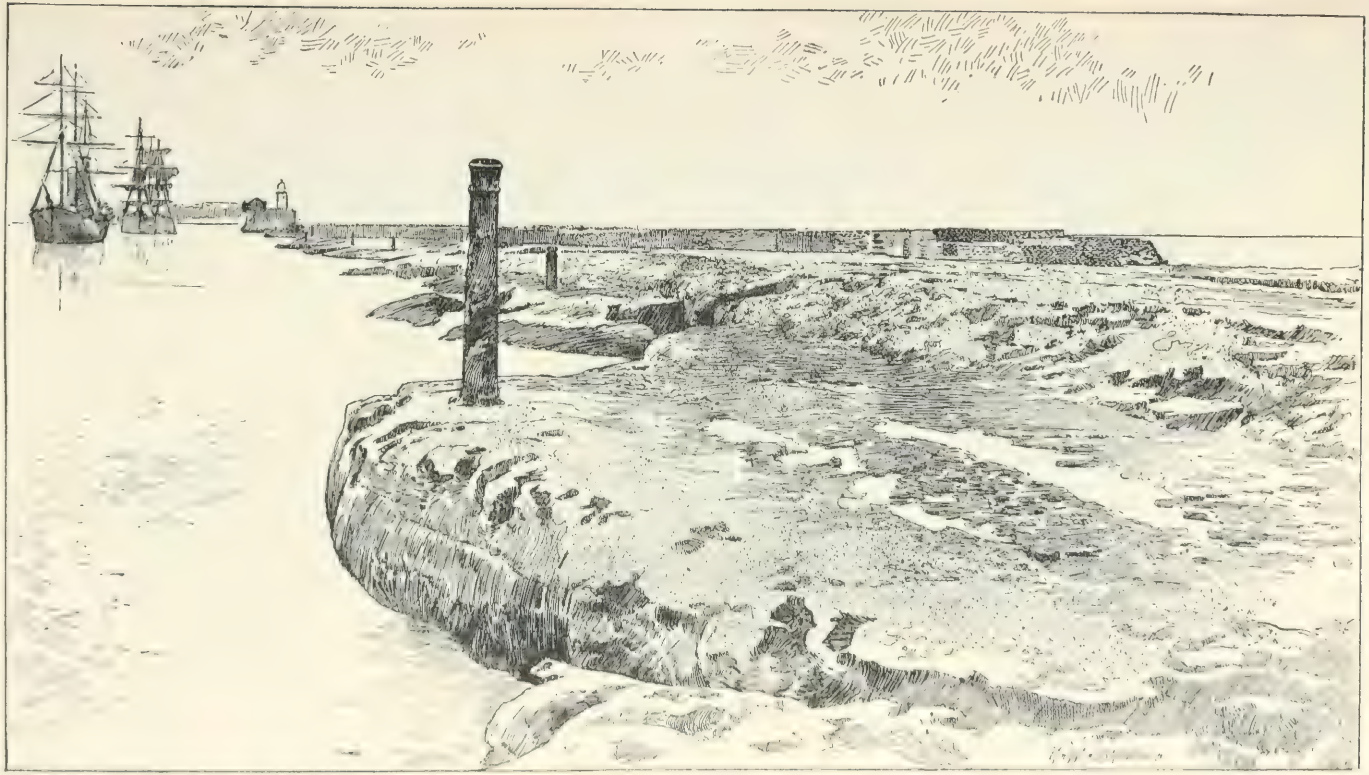

FIG. 33. Landward side of the Pernambuco reef. From a photograph taken near the north end.

The two other holes bored in the reef, one just below the arsenal, and the other opposite the custom-house and near the mouth of the river, show a succession of sands, shells, and clays, but there is apparently no regular sequence in the order of these beds, as will be seen by the accompanying cuts copied from the map forming a part of Sir John Hawkshaw's report.

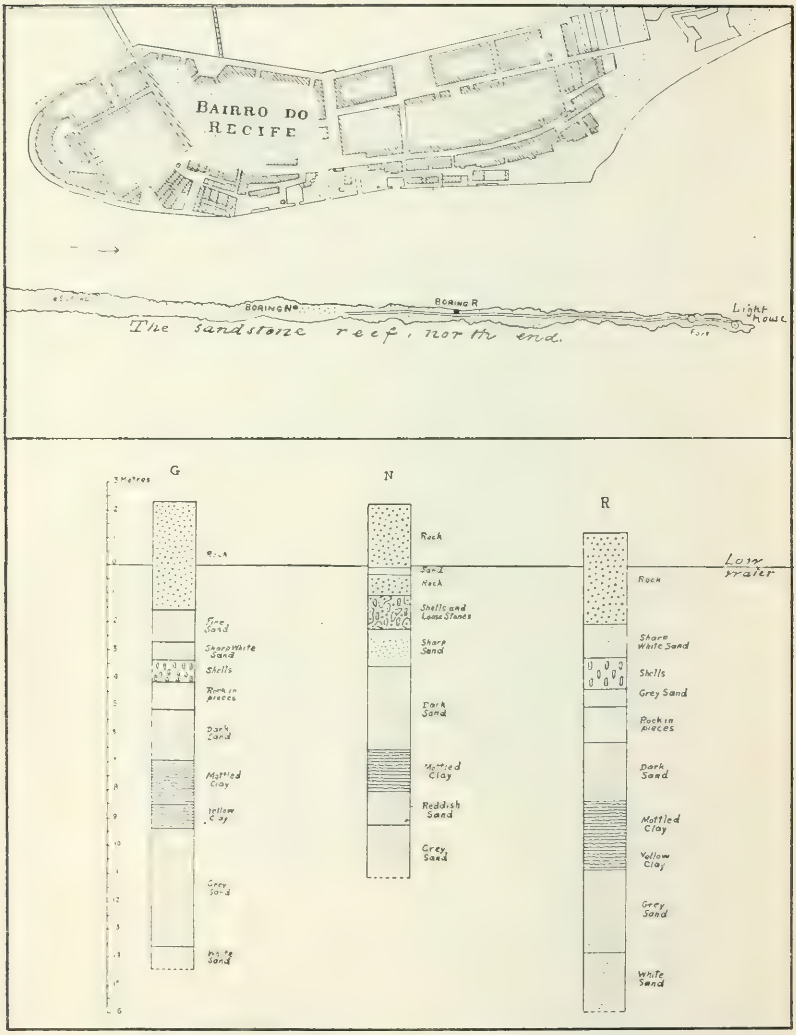
BAIRRO DO RECIFE
BORING N°
BORING R
Light house
Fort
The sandstone reef, north end.
G
N
R
3 Metres
Low water
Rock
Fine Sand
Sharp White Sand
Shells
Rock in pieces
Dark Sand
Mottled Clay
Yellow Clay
Grey Sand
White Sand
Sand
Shells and Loose Stones
Sharp Sand
Reddish Sand
Grey Sand

FIG. 34. Records and locations of borings made by Sir John Hawkshaw in the Pernambuco reef.

As elsewhere pointed out, I regard the clays found in the lower portions of these reef sections as evidence of the present beach line, and of the reef itself having been formed against or deposited upon an older beach that formerly lay further landward. The clays themselves are not beach deposits, but are the off-shore equivalents of beach sands.

That these stone reefs should have withstood the seas that break upon and over them, especially during heavy southeast gales, is one of the remarkable things about them, and especially so when we remember that only the upper part of the reef is consolidated. It is worthy of note also that when the reef is broken up the breaking seems to be due largely to the attack upon its landward side rather than to the force of the waves that break upon it from the sea.

At one place the force of the stream discharged into the harbor, and against the landward face of the Pernambuco reef, probably aided by the nature of the water, has undermined the reef. This is a common feature of the stone reefs all along the Brazilian coast, and is due in part to the fact that only the upper part of the reef is thoroughly consolidated.

In some places this kind of undermining has led to the breaking up of the reef, and the surface blocks now lie strewn upon the bottom or tipped about in confusion.

The fact that the outer face of the reef is not attacked more vigorously by waves is due to the protection afforded by the great quantities of Serpulae, barnacles, seaweeds, and the like that coat its outer surface.

The beach reef at Piedade. — Following southward along the beach from the southern end of the Pernambuco reef at Bôa Viagem by the sea one has on the land side a low ridge of sand some four metres high — the continuation of that at Bôa Viagem — and behind this the fresh-water marshes and Lake Curcurana. The topographic surroundings are therefore very much the same as those about the southern end of the Pernambuco reef.

The first signs of a stone reef in this direction are at the Piedade church, less than a mile south of Bôa Viagem. At this place there is a small beach reef about a hundred metres long. The rock is quite hard, but not flinty, and is of the same yellowish color as the beach sands. Its surface is etched in holes and overgrown with a thin coat of green seaweeds.

The seaward dip of these rocks is clearly shown, and the following angles were noted: 4½°, 5°, 6°, 6½°. The following dips of the beach sands alongside were noted: 4°, 4½°, 5°.

The stone reef at Venda Grande, Pernambuco. — Sixteen kilometres south of the Pernambuco lighthouse, at a small village known as Venda Grande, is a small but interesting stone reef. This reef connects with and is buried by beach sands at its southern end, four hundred metres north of the Venda Grande. Toward the north it draws gradually away from the beach, so that its northern end is two hundred metres off the beach.

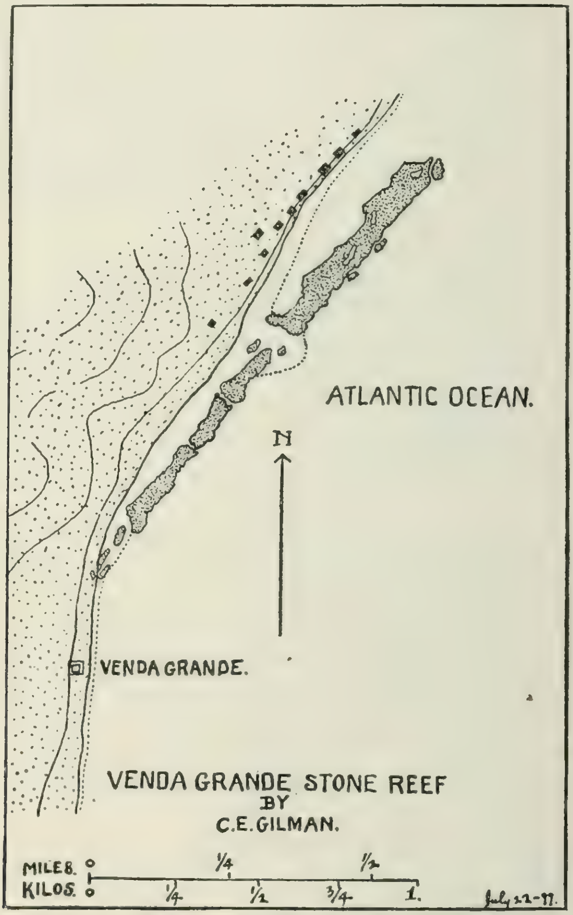
ATLANTIC OCEAN.
N
VENDA GRANDE.
VENDA GRANDE STONE REEF
BY
C.E. GILMAN.
MILES. 0
1/4
1/2
KILOS. 0
1/4
1/2
3/4
1.
July 22-99.

FIG. 35.

It has a total length of 1.6 kilometres, including the fragments on the beach. Unlike most reefs of the kind it ends abruptly: there are no signs of a submerged continuation of it beyond the northern end exposed at low tide. The axis of this reef points straight toward the lighthouse at Pernambuco.

Near the northern end the reef has the profile given below.

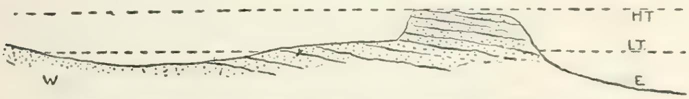

Fig. 36. East-west section across the stone reef at Venda Grande.

The top of the reef is pretty well covered with barnacles and worm tubes. These barnacles and Serpulae seem to start most readily and to thrive upon the stone legs or sharp points left by the etching of the reef rocks. The surface pools contain heads of *Porites.*

The rock is a yellowish, rather coarse sandstone, with many fossil molluscan shells in it. Shells of the same kinds are found in the sands in the breaks, and on the beach behind the reef. The rock is as hard as any seen on the reefs, — quite quartzitic in fracture.

The stakes of an ancient fish-trap are still standing on this reef, the posts apparently driven in the hard rock. Upon inquiry it was learned that these stakes were not driven in sand which subsequently hardened, but that the holes for them were drilled in the rock.

In some observations made upon the slope of wet sand behind this reef I found the steepest angle at which they stood to be 24°. This, however, was a face of false and not of true bedding.

The Gaibú stone reef. — Gaibú Bay is the embayment immediately north of Cape Santo Agostinho. At its southern end rise the granite hills of the cape surmounted here and there by Tertiary sediments. At its north end is the promontory of Pedras Pretas, a rocky point of black porphyry hills not shown on the hydrographic chart. The porphyry hills stand boldly out in the ocean; inland they are capped by the Tertiary sediments; nearer the sea these sediments have been removed by denudation, and only the quartz and other pebbles left scattered over the surface of the porphyry.

Between these two prominent points runs a line of Tertiary hills more or less notched on their edges, but swinging inland so as to form a semicircular enclosure for the Bay of Gaibú. Between the hills and the bay is a strip of flat land, partly mangrove swamps, partly fresh-water marshes, and near the beach dry sands and some dunes.

There are three small streams flowing from these flat lands: one of them discharges at the village of Gaibú at the extreme southern end of the bay, another about one third, and the other two thirds of the way from Gaibú to Pedras Pretas.

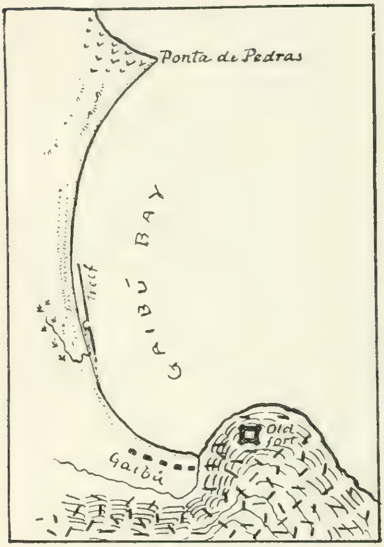

Fig. 37. Gaibú Bay.

Lying along the beach of Gaibú Bay, but here and there a little way out from it, is a sandstone reef extending nearly all the way from Pedras Pretas to the edge of the village of Gaibú. It is three kilometres or more in length and varies in width from forty-five to two hundred and forty metres, — a remarkable width for a stone reef. At low tide it stands two metres out of water at its highest points. It has a gentle seaward dip. The rock is of the ordinary sugar-brown sandstone and contains an abundance of fossil marine shells. The surface has the etched appearance so characteristic of the stone reefs.

The accompanying photograph (Plate **51**) taken from the granite hills south of the bay shows the southern end of this beach reef.

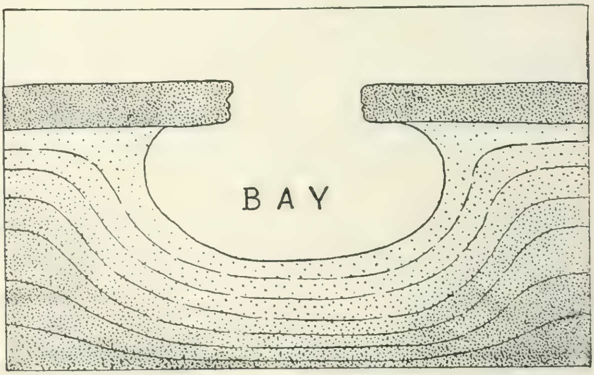

Fig. 38. Plan of a miniature bay behind a break in the Gaibú reef.

South of the middle of this reef is a small break through which the waves have been able to encroach upon the beach and to form a miniature bay protected by the ends of the stone reef.

There are many dressed and half-dressed building stones buried in the beach sands about the southern end of this reef. These stones are supposed to have been left here by the Dutch, as no one seems to know when they were taken out. It used to be supposed that the reef rock used at Pernambuco and Olinda for architectural purposes all came from the Pernambuco reef. It appears, however, that the Gaibú reef was the source from which some, perhaps most, of this stone came. This reef protects no harbor, and, being close to Pernambuco, and in a bay where boats could readily be loaded, it offered a convenient source of supply of these excellent building stones without trespassing on the Pernambuco reef, which had greater value as a protection to the port.

The stone reef south of Cabo Santo Agostinho. — The finest stone reef on the coast of Brazil is the one lying immediately south of Cabo Santo Agostinho in the State of Pernambuco. No steamers enter the port behind this reef and no highways cross the hills of the Cape above it; being thus of but little commercial importance, the reef is only slightly or not at all known. Recent charts represent it in a conventional fashion. The best map I have seen of it is that of Lichthart, the Dutch cartographer, made more than three hundred years ago, and the only views of it hitherto published are the woodcuts given in Liais' *L'Espace Céleste* (pp. 542, 546).

As in other cases, we are concerned to a certain extent with the physical features of the country on the land side of the reef. In this instance these features are so broad that their relations to the history of the reef are not so clear as they are in the cases of several of the small reefs with a similar history, but with a more compact topography.

The features of the region as a whole can be seen best from the high hills on the southern side of the cape. The view is superb. To the left the long straight reef stretches away to the south, a vanishing line. Behind this is the bay with one straight side against the reef, while the other curves in and out to meet the three streams, — the Merepe, the Ipojúca, the Tatuóca, and the Suápe, that enter it from the flat lands on the west. Here and there through this flat region one gets a glimpse of the shining waters of these streams, but for the most part they are hidden by the forests that cover the valley.

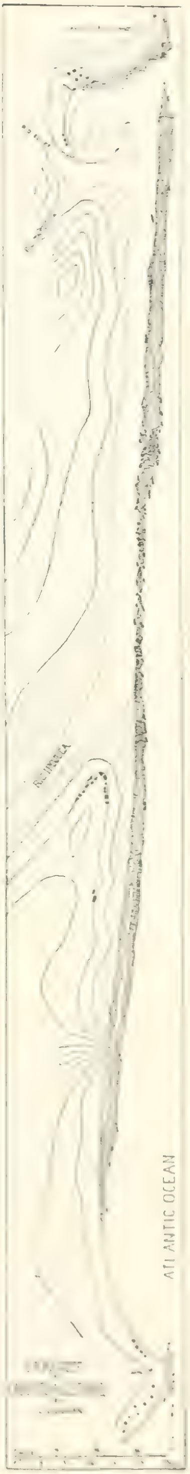

FIG. 39.

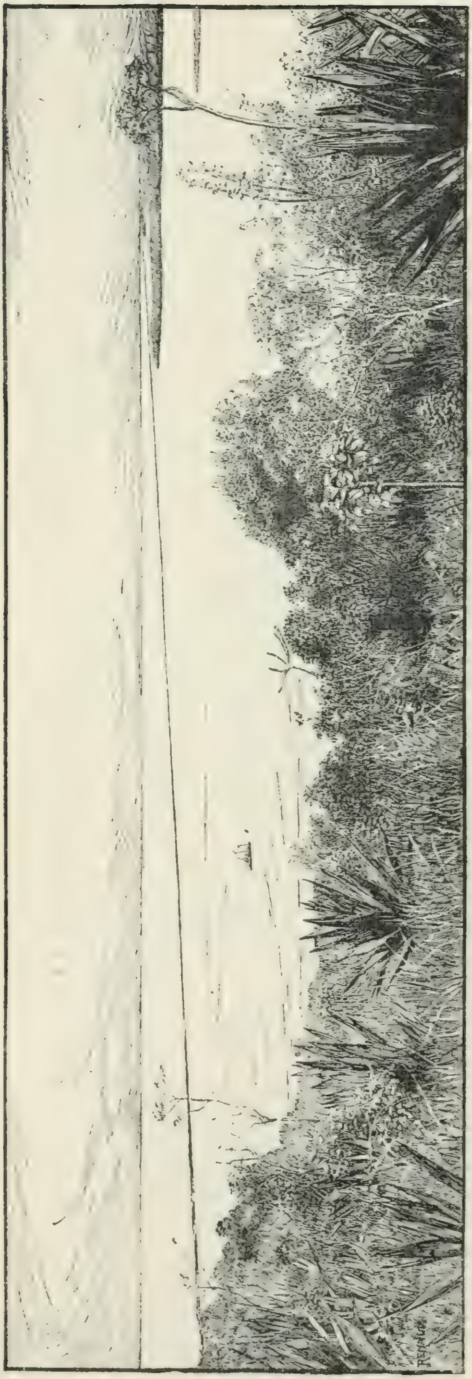

Fig. 40. Panorama of the stone reef south of Cape Santo Agostinho. From photographs taken from the Cape.

Over this valley only a few small isolated hills rise above the general level. The bay seems shallow save opposite the Barra do Suápe, the only big break in the reef, where the scour of the tides has kept the silts from accumulating.

The hills that face the bay at the cape are mostly crystalline rocks, granites, granite-porphyries, and altered eruptives, with patches of Tertiary (?) sediments lying over and against them. These hills are about fifty metres high. From the cape at the old fort they strike westward and after following that direction for several kilometres swing southward and finally approach, but do not quite reach the sea again at Serrambý Point, some thirty odd kilometres from the Cape. These hills are of pretty even elevation where they are near the coast, but nothing can be said here of their forms or elevation at the west edge or bottom of this ancient embayment.

On the plain just

south of the Rio Tatuóca is a small isolated Tertiary hill, and the hydrographic chart shows another of similar form a little further south.

The essential features of the geology of the region consist of a ridge of granite and granite porphyries, and other crystalline and metamorphic rocks of the Cape having an east-west trend, and with Tertiary sediments deposited against and over them. Denudation has stripped off most of the beds that lay upon the Cape crystalline rocks, and has carved out the embayment that now opens south of it. The shore of the bay from the Barra do Suápe to the village of the same name is all of crystalline rocks; a little west of the village a promontory of Tertiary (?) beds projects into the valley. This hill is of mottled yellow, red, and white clays and sands; there are no granites exposed where the Rio Suápe washes its base.

At the village of Suápe the beach on the flat is all sandy, and barely high enough to keep the salt water at high tides from flowing over into the fresh-water marsh lying just west of it. Tradition says that the bay at this northern end is rapidly cutting away its western shore. The coco palm stumps standing in the bay from one hundred and fifty to two hundred metres out from the present beach bear out this tradition.

At low tide great sandy flats are uncovered in the bay. At its southern end and south of Cambôa Point the bay is but a narrow and shallow pool some twenty to fifty metres wide, into which the tide-water backs. On the sea side of this pool is the wall-like reef, and on the land side a bank of white sand five or six metres in height. The sand flats about the mouth of the Ipojúca and in this arm of the bay swarm with myriads of little fiddler crabs. These sands also contain a great number of delicate pink shells of bivalves.

The sand ridge on the land side is a wind accumulation; behind it the country drops off again to a somewhat lower level.

The Cabo Santo Agostinho reef properly speaking begins on the beach of the cape itself, just north of the Barra do Suápe and a few hundred metres north of the old fort. The rocks of the cape just here are coarse-grained granites, and the reef rock lies unconformably against, and attached to, these granites. There are several of these reef fragments separated from one another by breaks of various lengths and strewn along the beach over a distance of a kilometre to the north of the fort. The section is essentially the same for all these remnants.

The fragment nearest the fort is fifty-three metres wide by forty-five metres long. The next fragment to the north is ninety metres long and about fifty metres wide. All these reef remnants have a gentle seaward slope, rise about as high as the high tides, and have flat tops, — a topographic configuration in strong contrast with the rounded outlines of the granites. The reef sands originally sifted into the crevices in granites and hardened so as to enclose granite blocks here and there. The rock is a rather fine-grained quartz sandstone of a light brown color. It contains a few fossil shells.

These fragmentary beach reefs and the Cape of Santo Agostinho itself are separated from the great stone reef by a gap or break four hundred metres wide and, according to the hydrographic chart, 4½ fathoms deep. This gap is known as the *Barra do Suápe.* It is the only break in the great reef through which *barcaças* can enter the bay and the rivers that flow into it.

If the Suápe break were restored, the total length of the Cape Santo Agostinho reef from the cape to where it disappears beneath the sands north of the cape would be thirteen kilometres. How much of its southern end is buried beneath the beach sands we have no means of knowing. Even to-day, taking out the various gaps, we still have preserved a reef something more than twelve kilometres in length.

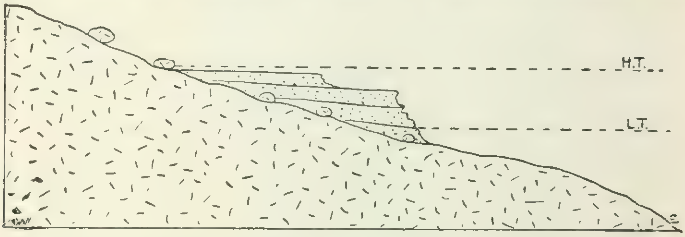

FIG. 41. Section showing the relations of the stone reef and granite at Cape Santo Agostinho.

A striking feature of the Santo Agostinho reef is the long tide-pools on its surface and running lengthwise of it. Toward the northern end these pools are not so long or so deep, but toward the southern end there is one pool a metre deep and nearly three kilometres in length. In the photographs taken of the reef near Cambôa, the reef has the appearance of being double; and in a sense it is double, for the pool is made by a softer series of beds that dips beneath the harder ones that form the reef's seaward face, and overlies another series of harder ones that forms the landward face.

From end to end the reef is nearly straight; there is but one slight seaward bend opposite Cambôa Point. The surface is for the most part very even and nearly level along any lengthwise section. The first break is 3.6 kilometres south of the Barra do Suápe. South of this there follows a series of breaks at various distances from each other over a distance of three kilometres. Beyond this shattered portion the reef is solid and unbroken to where it joins the land five and a half kilometres further south.

It is worthy of note that the breaks in this reef are in front and to the north of the mouth of the Rio Ipojúca, whose waters are here deflected to the north. Water runs through and beneath the fragments that lie scattered in the bottoms of these breaks in the reef.

There is but little difference in the height of the reef throughout its entire length. In front of the Cambôa residence it is said to be a little higher than near the Suápe bar, but the difference in level is not enough to be apparent to the eye.

The north end of the reef just south of the bar is from ninety to one hundred metres wide; along the fractured section north of the mouth of the Ipojúca it is narrower than elsewhere, and in places here it is not more than thirty metres wide; opposite the Cambôa residence it is one hundred and fifty metres wide; and at the south end where it joins the land it is from one hundred to one hundred and twenty-five metres wide.

At low tide the top of the reef seems to be about two metres high (above low-water level); at high tide it is almost completely covered, only a few blocks scattered over the surface projecting above water.

The following cross-sections made at different points will give a fair idea of its profile. It should be added, however, that by searching along the reef one could find here a section to match any or almost any section observed on any of the stone reefs of this coast. In the main, though, this particular reef is, through its solid portions at least, less broken on the margins and less open to attack than most of the stone reefs.

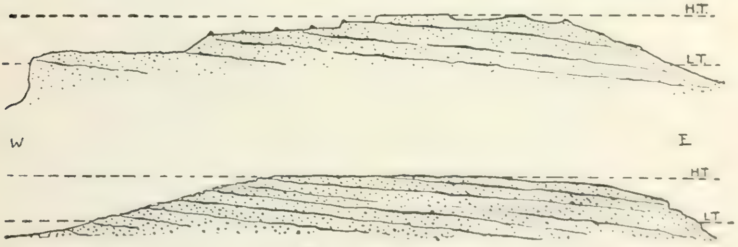

FIG. 42. Sections across the stone reef south of Cape Santo Agostinho.

This last section is a typical profile of much of the Cabo Santo Agostinho reef. The outer face is not broken off vertically, but slopes rather abruptly and with a somewhat irregular face beneath the sea.

At Cambôa Point the reef is solid and vertical on its landward face. At and south of the Cambôa residence (1.4 kilometres south of Cambôa Point) the section is as follows:

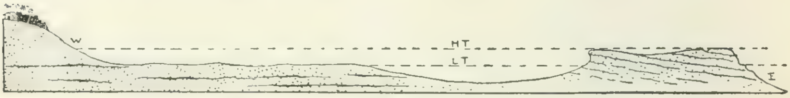

Fig. 43. Section of the Santo Agostinho reef at Cambôa.

The features of this portion of the reef are well shown in Plates **53** and **54**, from photographs taken July 25, 1899.

As the southern end of the reef is approached, it disappears beneath the sands of the beach, and the section is thus:

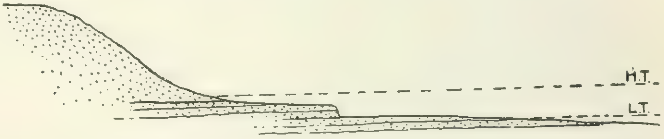

Fig. 44. Across Cape Santo Agostinho reef at its southern extremity.

The great tide-pools that lie on top of and in the axis of the reef have already been mentioned. These pools abound in corals and calcareous seaweeds, and contain some corallines; and it may be fairly said that small coral reefs have started in these pools. The corals are mostly of small species, *Porites*, *Favia*, and *Agaricia*. In some of the shallower pools some of these calcareous growths have been broken off by the surf, rolled about like pebbles, and tossed over on the sandy beach behind, or left to be rolled still more in the reef pools.

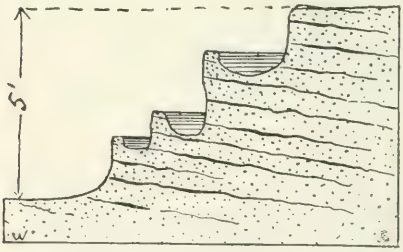

Fig. 45. Tide-pools on the landward edge of the reef.

There are still other pools on the surface and in the axis of the reef but on its landward face; as shown in the accompanying profile, they are especially noticeable.

Many of the minor pools on top of the reef contain calcareous growths and seaweeds in cavities built up by Serpulae, etc.

Sometimes these calcareous growths fasten themselves on points of sandstone. Here and there sea-urchins with their burrows cover considerable areas, especially on the seaward faces of the reef where the waves constantly renew the water. These burrows are for the most part parallel with the currents that flow across them, and hence mostly at right angles to the trend of the reef. The following is the plan of a few of these burrows.

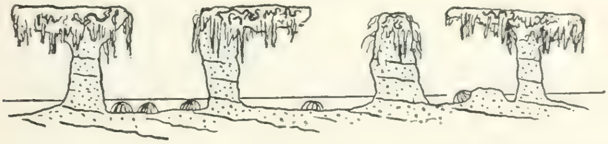

FIG. 46. Points on surface of sandstone reef covered with Serpulae and seaweed.

These pits are only partially occupied by sea-urchins. They contain also corallines and some corals (*Porites*). They are cut in the hard surface sandstone, and are from three to ten centimetres deep. The edges of these pits are generally overgrown with Serpulae. In the pools of the reef's surface are occasionally found water-worn lumps of Serpulae tubes, apparently broken from the reef and rolled by the waves.

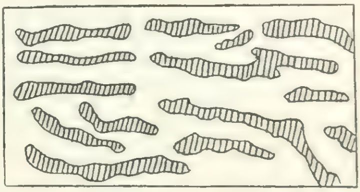

FIG. 47. Plan of the pits on the surface of Cabo Santo Agostinho reef.

There are some cracks in the surface of the reef, most of them running lengthwise of it. The cracks become more abundant and more varied where the gaps occur, and they continue so clear across the fractured area. In other portions of the reef they are less abundant than on the other stone reefs examined.

The rock of this reef is, on the whole, finer of grain than that of the average. It contains some pebbles, some of them black iron-colored ones washed from the mottled Tertiary plateaus. Most of the rock is hard, light, sugar-brown sandstone cemented with lime carbonate.

Everywhere the body of the reef is covered with Algae; on top they are mostly green. It is etched a little on the landward side, probably by the acid waters of the streams, just enough to bring out the bedding.

but it shows very little or no signs of active or rapid wearing of the rocks.

The surf that breaks against the outer face of the reef is heavy, for it comes in from an open and deep ocean where there are no coral reefs to break its full force. The depth of 4½ fathoms marked on the hydrographic charts outside comes close up to the reef along most of its length. It is remarkable that this violent surf has not affected the reef more than it has. There are but few blocks tossed upon the top of it; one of these, however, weighing more than forty-eight short tons, has been hurled almost the entire width of the reef, and now rests within a few metres of its inner margin.

Mention should here be made of the possible relations of the Cape Santo Agostinho reef to a small coral reef just off Cúpe Point. The stone reef is in line with the beach to the south for half a kilometre; the beach then swings eastward to and around Cúpe Point. East of this point a coral reef about six hundred metres long lies a few hundred metres off shore. Now the Cape Santo Agostinho reef, like the others, has a gentle seaward dip. If this reef continues southward to and passes beneath the sands west of Cúpe, its dip must carry it beneath the coral reef that lies east of that point. (See map of Cape Santo Agostinho reef, p. 71.)

The beach rocks at Porto de Gallinhas. — Porto de Gallinhas is a little village on the coast fifteen kilometres south of Cape Santo Agostinho. It is on a sandy flat with fresh-water marshes between the village and the hills just west of it.

There are some rocks of recent origin at this place which, on account of their possible relations to the coral reef off the coast, are worthy of mention. These rocks are like the ordinary reef rocks, except that they contain rather more than the usual amount of calcareous Algae fragments. They are exposed when the tide is out at the large warehouse that stands on the edge of the beach near the anchorage. Again, south of the village, at the first westward turn of the beach, soft calcareous sandstones are exposed on shore by the recent encroachment of the sea. These beds have the usual seaward dip, which, if it con-

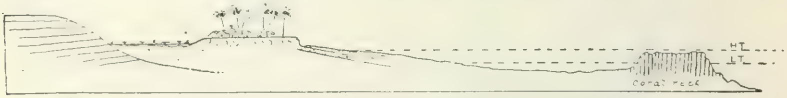

FIG. 48. Section showing the relation of coral reef to beach sandstone at Porto de Gallinhas.

tinues that far, must carry them beneath the coral reef that lies a few hundred metres off shore at this place.

The Cacimba and Serinhaem stone reefs. — The Rio Serinhaem enters the ocean in south latitude 8° 36′, just east of the island of Santo Aleixo. The Cacimba and Serinhaem reefs lie across the mouth of this river and in front of the flat lands immediately north of it.

The Cacimba reef is largely on the beach at the bottom of the embayment between Ponta do Serrambý and Rio Serinhaem, while the Serinhaem reef lies across the mouth of the river and extends well to the north, affording partial protection to the embayment west of it.

The country west of these reefs consists of a narrow strip of sandy land next to the beach, with mangrove swamps and sandy flat lands behind. These low flat lands about the mouths of Rios Serinhaem and Trapiche extend back to the foot of the Tertiary hills that rise a few kilometres inland.

At the town of Barra de Serinhaem, soft black Tertiary sandstones are exposed at low tide along the river bank for a distance of several hundred metres.

The northern end of the Cacimba reef begins on the beach south of Ponta do Serrambý at a place called Cacimba. A sand bank three metres high rises on the land side of it, and two hundred metres west of the beach a mangrove swamp follows southward parallel with the shore.

The northernmost four hundred metres of this reef lies upon the beach; then follows a break, beyond which it touches the beach at only one point. It is a striking and interesting fact that the southern end of this reef curves gently eastward with the beach, keeping always parallel with it and from forty to sixty metres away from it.

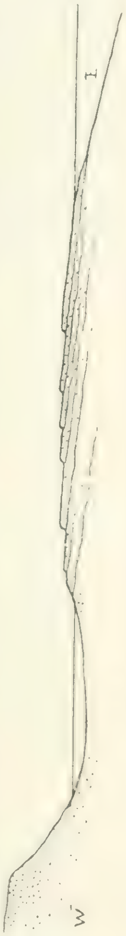

Fig. 49. Section across the Cacimba stone reef.

The south end of the Cacimba reef is more or less broken, until at last it appears only as isolated patches, and finally drops in behind or landward of the Serinhaem reef, and comes to an end.

About its northern end this reef stands fully two metres out of water at low tide; near its south end it is not quite so high. The surface is much cracked, broken, and etched lengthwise, and there is a great number of holes, from three to seven decimetres across, eaten straight down into the body of the rock. This peculiar form of etching or decay has been seen on no other stone reef.

The bedding is plainly visible, and several observations show that the dip is seaward at an angle of from seven to nine degrees.

Here and there along the outer edge, the reef has been more or less undermined, and great blocks of stone have been detached and their outer edges have sunk.

The surface of the reef is unusually rough, ragged, and etched, and many loose blocks lie over the top. The rock is very hard and quartzitic in fracture, and rings when struck with the hammer.

Eight hundred metres south of its northern end, there is a break in this reef through which the sea has been able to cut out one of the beautiful little semi-lunar bays mentioned and described elsewhere in this paper.

The Serinhaem reef is a straight one lying between the shore and the island of Santo Aleixo. Its total length is between three and four kilometres, and its bearing north 50° east, magnetic. The south end of the reef is about half a kilometre south of the mouth of Rio Serinhaem, while the north end projects boldly across the embayment south of Ponta do Serrambý. The north end is broken, and its extreme point in that direction is represented only by sunken rocks. Near its middle, and opposite the river's mouth and a little south of it, this reef is a double one; or, if the Cacimba reef be considered, they may all be looked upon as a treble reef. Of this group the Serinhaem is the outer one, the Cacimba reef is the landward one, while a third reef lies about halfway between them.

This middle reef is more or less fragmentary, yet clearly defined both in its position and its direction. It is parallel with the reefs on both sides of it.

It was noted the last time these reefs were visited (July 26, 1899), that the muddy waters of the Rio Serinhaem were discharging to the southward and not northward, as do most of the streams along this part of the coast.

The stone reef of Santo Aleixo. — Santo Aleixo is a small island opposite the Barra de Serinhaem, and about two and a half kilometres from the main land. It is also known to navigators as Donally's Island. It is eight hundred and eighty-three metres long, its longest axis being north-south. The body of the island is of quartz porphyry,[1] which on the southeast corner rises to a height of twenty-one metres. On the western side of the island is a small bay, south of which is a quarry in the igneous rocks. Next to the quarry there are remnants of a calcareous fringing reef upon the beach, extending from that point to the southeastern point of the island. Along the shore of the little bay on the south side of the island is a piece of consolidated beach or stone reef. The rock is made of bits of shells, corals, sands, etc., exactly like the unconsolidated sands of the present beach. It is not hard and solid like the reef rock of Rio Formoso, but is soft and porous.

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[1] In his *Espace Céleste*, p. 548, Liais says the rocks of Santo Aleixo are eurities and diorities; in his *Climats Géologie*, etc., he says they are amphibole and mag-

This reef is between one hundred and fifty and two hundred metres in length, is from four to five metres wide at the widest, and is so high in places that only the very highest tides wet it entirely. On the land side it is buried beneath the beach sands, but toward the sea it is abrupt in places. It seems to be wearing away rapidly.

The sandstone reef of Rio Formoso.[1] — Rio Formoso is an estuary in the State of Pernambuco, sixty kilometres southwest of the city of Pernambuco, and thirty-four kilometres southwest of Cabo Santo Agostinho. An isolated Tertiary hill stands back from the coast west of Gamella, and another stands just north of Rio Formoso. Against these hills lies a plain of later geologic age, that rises about eight or nine metres at most above high tide-level. Northwest of these hills, and north of the estuary, is a broad, low, flat country partly covered by loose sand and growing orchards of caju trees and other caatinga plants, and partly also by extensive mangrove swamps. Beyond (west of) this flat valley rise the low, approximately flat-topped table-lands of the interior, — in this vicinity composed of granites, gneisses, and crystalline schists.

The structure and character of the Tertiary hills is shown where the tides of Rio Formoso have cut away the foot of the hill upon which stands the Church of Nossa Senhora da Guadalupe. The rocks are soft, white and gray sandstones, and red and yellow mottled clays dipping gently seaward.

The rocks that lie against these Tertiary hills are well exposed all

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nesian porphyries (p. 260). My determination of this rock was made after a microscopic examination by the late Dr. George H. William from material gathered by myself.

(The Cretaceous and Tertiary geology of the Sergipe-Alagôas basin of Brazil. By J. C. Branner. Trans. Amer. Phil. Soc., 1889, XVI., p. 404, foot-note.)

In his *Climats Géologie, etc., du Brésil* (p. 252), M. Liais speaks of Tertiary sediments on the island. The beds he refers to are these recent sandstones.

[1] This description of the Rio Formoso reef has been published in Portuguese by the Instituto Archeologico e Geographico Pernambucano at Pernambuco, Brazil.

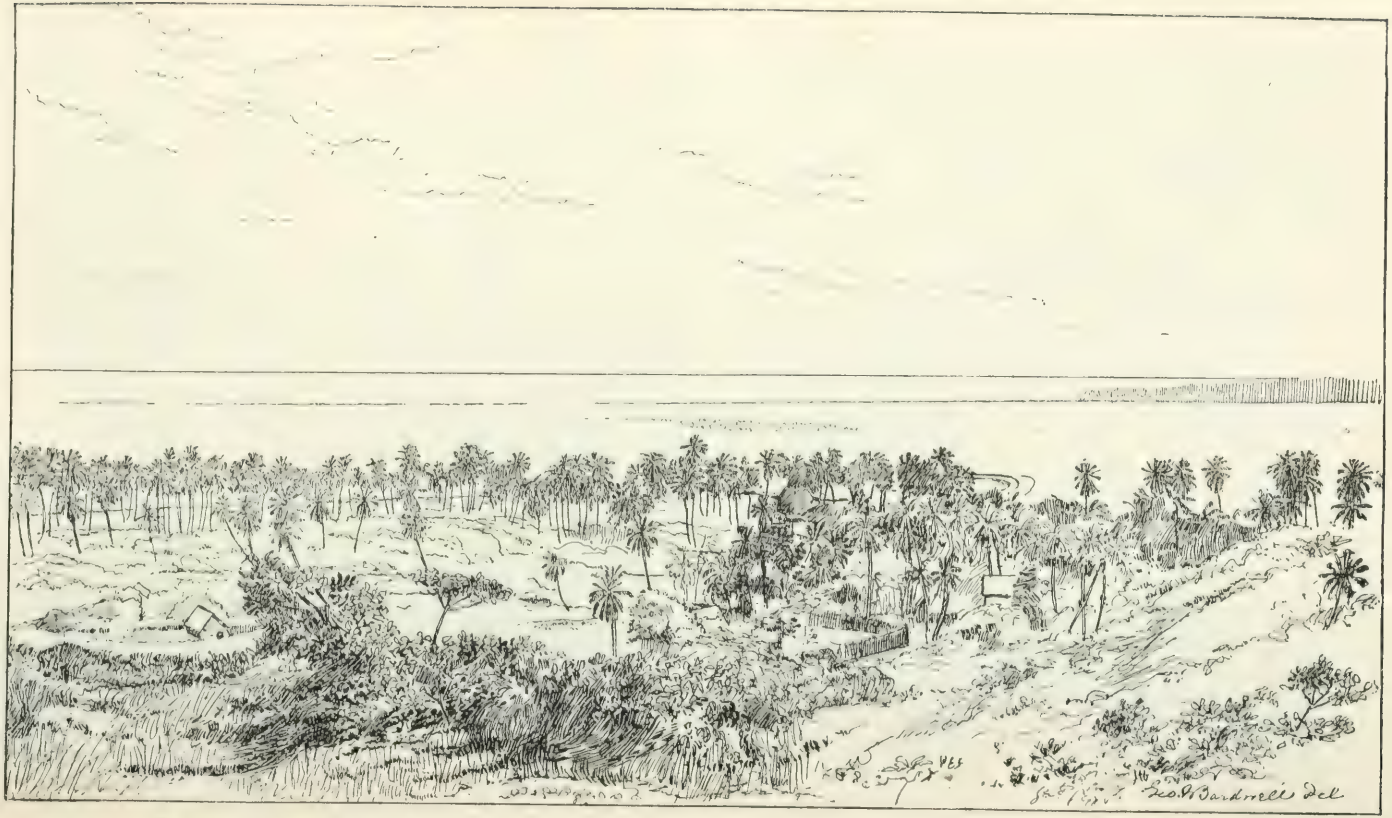
Geo. P. Bardwell Del

FIG. 50. View of the sandstone reef at Rio Formoso. From photographs taken from Guadalupe Hill.

along the beach between Gamella and Guadalupe. The section and geologic relations of these beds are shown in the sketch on p. 30.

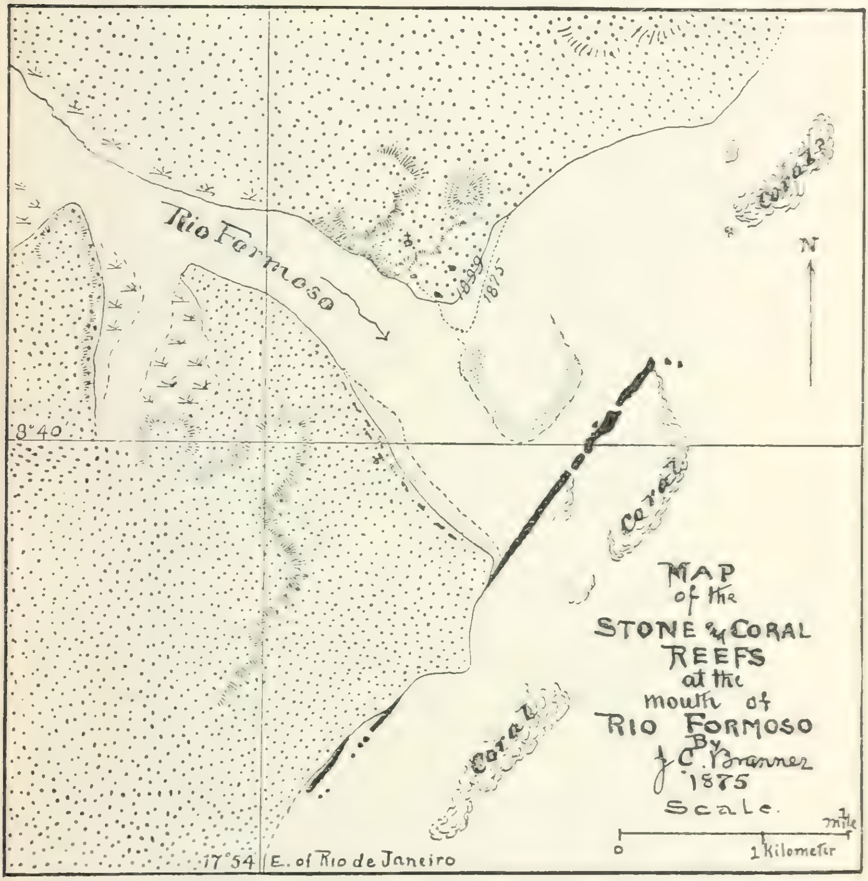
Rio Formoso
1899
1875
Coral?
N
Coral
Coral
MAP of the STONE & CORAL REEFS at the mouth of RIO FORMOSO By J. C. Branner 1875
Scale
¼ mile
0
1 Kilometer
8°40′
17°54′ E. of Rio de Janeiro

FIG. 51. The dotted line on the north side of the mouth of the river shows the position of the shore in 1875; the solid line to the west shows the shore in 1899.

Pure white quartz sand	10–20′ [1]	
Black soft sandstone	8′	
Yellow clay seam		1″–2″
White soft sandstone	7′	
Blue sandy clay at base	?	

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[1] These white quartz sands are well adapted to the manufacture of glass. The bed in places is four metres thick, but for most of the distance from Gamella to where the sands abut against the Guadalupe Tertiary hill, they have been blown

The lowest two beds of this section, below the yellow clay seam, are Eocene Tertiary, and similar to the beds exposed on Rio Formoso, south of the Guadalupe church. The beds above the clay seam rest unconformably against the early Tertiary as shown on p. 30.

The sandstone reef of Rio Formoso (not including here the southern end buried by the sands and to be spoken of further on) begins on the southwestern side of the river or estuary on the Praia dos Carneiros, and extends northeast in an almost straight line across the mouth of this stream, and at right angles to it.[1]

The northern end of the reef curves westward slightly but distinctly; this curve, however, is not apparent on the small-scale map given herewith.

On an average, the reef is twelve metres in width, and stands a little more than one metre above water at ordinary low tides. Its entire length is two thousand and seventy metres. Its general appearance varies somewhat with the locality: near the south shore, to which it is united, it is broad and flat, and comparatively smooth. Structurally this reef has a slight but very apparent seaward dip. In surface contour, the outer or oceanward side generally slopes at an easy angle along the whole length of the reef, and as it dips beneath the water becomes covered by corals and other marine animals and plants and their skeletal remains. In many places the top is covered by rough jagged points left by the wearing or etching away of the softer or more soluble surrounding parts of the rock. These points are a third of a metre or less in height, and often so close together and so sharp as to make walking through or over them almost impossible. They are extremely hard, and can be broken only by a sharp blow with a heavy hammer. When struck, the larger ones ring with a clear metallic

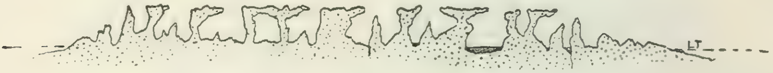

FIG. 52. Profile of the etched sandstone reef at Rio Formoso.

up from the seaward side, and heaped upon the original bed, until they are from five to seven metres thick, and three or four hundred metres wide. If there should be any demand for such materials in this part of Brazil, a short tramway along the front of these beds could deliver the sands on board of *barcaças* at the foot of the Guadalupe hill.

[1] Liais speaks of a triple line of reefs at Rio Formoso. (*L'Espace Céleste*, 549.) There are no such reefs at this place unless one considers the patches of coral outside the stone reef as such.

sound. The surface of the Rio Formoso reef, however, is not, on the whole, as ragged and rough as those of many other of the stone reefs.

The broken stone generally shows quartz sand mixed with some pebbles and shells. The pebbles are also of quartz, and the shells are of bivalves, gasteropods, etc., such as live at present along the coast in the vicinity. The shells most abundant are the prettily colored bivalves *Venus*, popularly known here as *mariscos*.

In many places, in fact, in almost all parts of the reef, cracks appear to have been formed and then to have been filled up again with sand that has hardened like the rest of the reef. These cracks have generally the same direction as the reef, but they sometimes cross it at right angles, and at other times diagonally. In two places the reef has small breaks nearly or quite through it, crossing diagonally, and with the appearance of being due largely to the presence of the cracks.

From the land end on the south outward there is no break of importance until about halfway the whole length of the reef, where there is a baretta or passage for canoes and *jangadas*. This break is known as the *barreta das jangadas*. It is here that the reef receives the full force of the ebbing tide as it comes down from the river. From the *barreta das jangadas* to the outer end, the side facing the river is either perpendicular or overhanging. In the *barreta* itself the rocks in the bottom of the passage are hard and appear to be the same as those on the surface of the reef at other places. I suppose the rocks in the bottom of the passage to have formerly stood even with the surface of the reef, but being undermined by the strong sand-laden currents, they have lost their support and fallen where they now lie. These blocks, or more properly slabs, are all large and broad, and of the same average thickness as the harder upper part of the general body of the reef.

From this place to the outer end, five hundred and seventy metres, there are two other breaks, both of them smaller and of less importance than this one.

The whole of the riverward face of the reef is undercut. Blocks have broken away where left without support, and in one place especially, very large pieces have fallen, and, with one end held fast by the sand and mud of the bottom of the channel, remain with the other end tilted high in the air. One of these is so high that it is not covered even by the highest tides; this one is popularly known hereabout as the Pedra de Nossa Senhora, or the Rock of Our Lady.

At still another place the reef is entirely undermined, while the surface rock still remains in place. A large body of water flows through underneath this bridge with every ebbing and flowing tide.

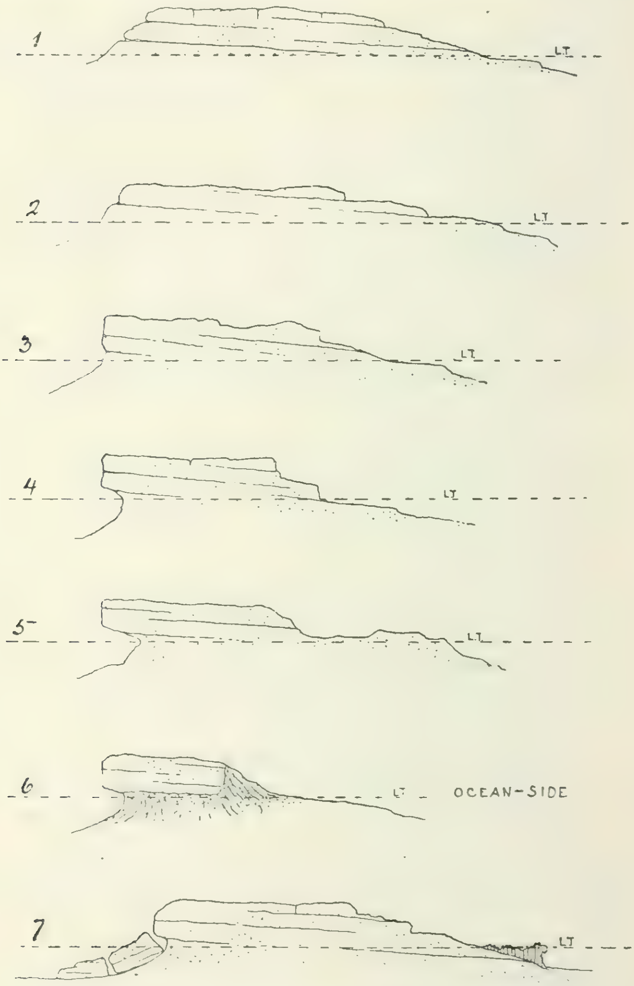

FIG. 53. Sections across the Rio Formoso sandstone reef.

Along the landward side the bottom of the channel next to the reef is covered here and there by huge blocks of stone like the upper part of the reef. There are tide-pools over the surface, especially near the landward end. At the outer end the reef breaks off abruptly, and there are no indications of a northward continuation of it, unless they be in the sunken rocks further out, and over which the waves break at low tide. These breakers lie in the axis of the stone reef.

There is a coral reef off shore at Praia da Gamella also in the axis of the stone reef; possibly it is built upon a base of sand rock.

The outer or northern end of the stone reef is covered with barnacles. A coral reef beginning here on the east side of the rock reef bends back toward the south, and, being separated from it by a channel, protects it from the force of the waves of the open ocean. It is only at their outward or northern ends that these two reefs are joined; the channel separating them becomes wider and wider till it passes the *Barreta das Jangadas,* and at this end it is more than a hundred metres in width. This channel has a bottom of coarse calcareous sand with very fine mud in some places. Corals and other organic calcareous growths have spread over the outer side of the sandstone reef, and in many places have grown upon the stone reef as a base until they are now near the surface of the water.

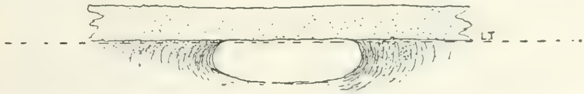

FIG. 54. Longitudinal section of an undermined portion of the stone reef, Rio Formoso.

It is noticeable that we here have corals thriving in front of a river mouth. The fact is that the stream is deflected to the north by the stone reef which thus protects the corals from the mud and fresh water entering from the river. A similar state of affairs is found at several other places along this coast.

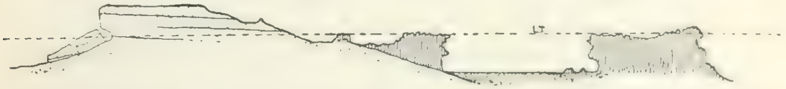

FIG. 55. Across Rio Formoso stone and coral reefs. The darker portions are corals.

From the land end of the stone reef, following southward along the sandy beach to a distance of eighteen hundred metres, there is another (or the same) stone reef joined to the land and running out into the embayment so as to make an angle of about twenty degrees with the beach. This reef is about seventy metres wide. Just where it joins the beach the rock is the coarsest seen in this vicinity, the pebbles being as big as pigeon's eggs. The piece is only short, being about three hundred metres long. Beyond this, however, there are several isolated patches lying in the direct axis of this portion and stretching halfway across the embayment or curve in the coast line north of Tamandaré. This bit of reef, together with the isolated fragments at its southern end, is in a line with the stone reef of Rio Formoso. Just behind or landward of this small reef, and about a hundred metres from it, there is still another sand reef lying along the beach. This on-shore reef is parallel with the outer one, but in composition it is softer, though of the same kind of material. It has a gentle dip seaward. Its seaward face is broken off squarely wherever the open sea strikes it.

There are also a few remains of hardened sand rock between the Rio Formoso reef and the high lands west of it, but these remains or bits are scattered, and without the linear arrangement that characterizes the stone reefs. One of these localities is at Gamella Point, where soft calcareous sandstone is uncovered by the encroachment of the sea. At the Guadalupe Point, where the sea is also encroaching, a soft calcareous rock is being uncovered at high tide-level, less than a metre below the surface of the sandy soil.

The map herewith, and most of the observations embodied in the part relating to Rio Formoso, were made by the writer in 1876. On revisiting the place in 1899 considerable changes were noticed in the beaches. At Gamella Point the sea was found cutting the land so that a large *Gamelleira* tree, that in 1876 was well up on the beach, and beyond the reach of the sea-water, is now a dead stump a dozen metres to the seaward of the high tide mark. Guadalupe Point is being cut away on the east side and filled in on the west. The holder of the property at this place states that he has lost more than a thousand coco palms by the encroachment of the sea during the last seven years. This point was mapped again July 27, 1899, and the two outlines are shown, with their appropriate dates, on the accompanying map.

The stone reefs of the Rio Sapucahý, Alagôas. — The Rio Sapucahý is a small river in the State of Alagôas entering the ocean about thirty kilometres (in a straight line) northeast of Maceio, and three kilometres northeast of the village of Paripueira. The country west of the mouth of the river is, like most of the northern coast of Alagôas, a plateau of Tertiary sediments cut across by the river, and a strip of low flat land, partly mangrove swamps and partly sand flats, intervening between the base of the hills and the ocean.

The Sapucahý stone reef lies right across the mouth of that river, and the stream debouches right and left round both ends of it. It is

1.08 kilometres in length, not including some submerged fragments at its southern end, is from fifty to one hundred metres off the beach, and stands nearly two metres out of water at low tide. It is not connected with the beach at any point, and is almost solid from one end to the other, being broken a little only near its southern end.

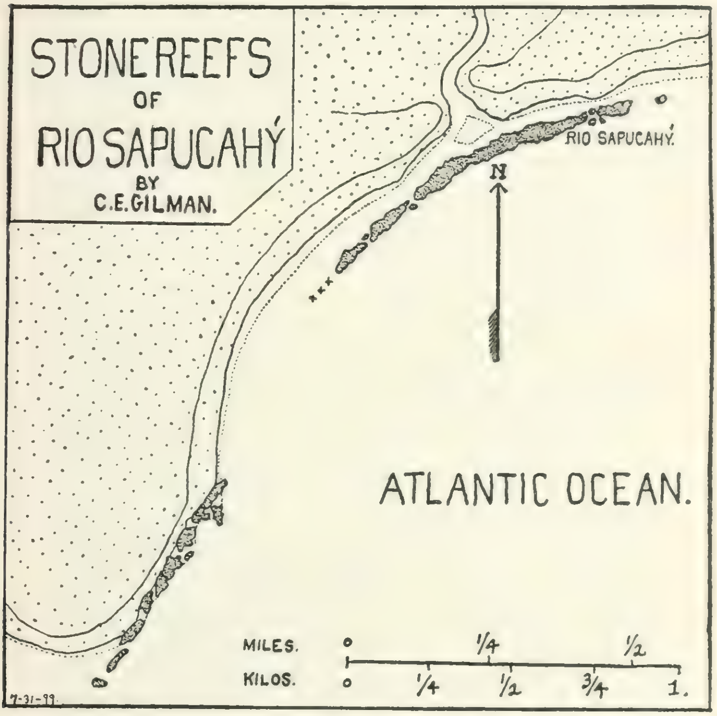

FIG. 56.

An interesting fact about this reef is that it has a gentle curve parallel with the beach behind it, — a peculiarity I do not remember to have observed in any other of these sandstone reefs.

Following the beach southward from the mouth of the Sapucahý, it curves gradually seaward and then back landward again, forming a sandy point, part of which is shown on the accompanying map. At a distance of 1.4 kilometres from the mouth of the Sapucahý, this sandy point laps over one of the coral reefs that here run parallel with the coast. And just at this point on the beach begins another reef of sandstone.

This particular reef is eight hundred metres long, not including some detached fragments lying beyond its southern end, and not shown on the map herewith, which would give it a total length of something more than a kilometre.

A fact of unusual interest in regard to this bit of reef is that *it overlies a dead coral reef.* The overlap is plainly visible at many places where re-entrant angles have notched the stone reef, or where large fragments have been left isolated but fast to the coral reef.

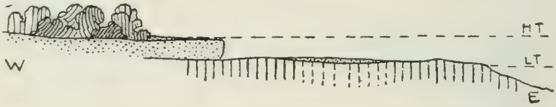

FIG. 57. Section across the stone and coral reefs at Sapucahý. The vertical shading on the right represents the coral reef.

The coral reef visible here at low tide is from one hundred to two hundred and seventy metres wide, measured from the outer margin to where it is overlapped by the stone reef or by the beach sands. This coral reef is almost perfectly flat and level. Not a single living coral could be found on its upper surface; the coral most abundant in the rock itself is *Porites.*

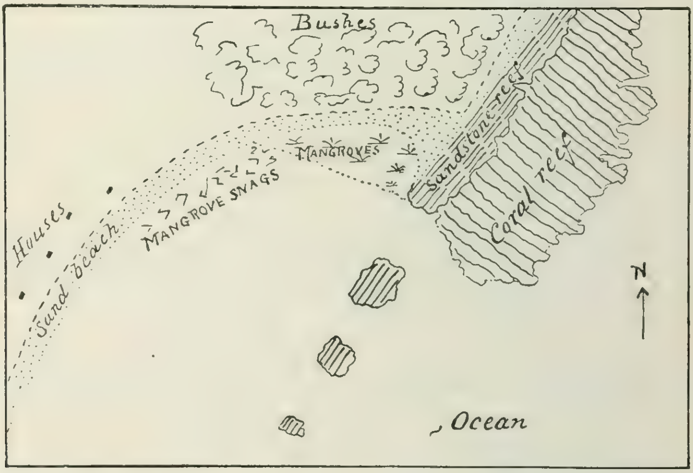

FIG. 58. Sketch map of the southwest end of the stone reef at Paripueira, State of Alagôas.

Outside or seaward of this reef is still another coral reef with which the inner one is not connected at the water's surface at least.

The sandstone reef lies at a higher level on the beach than the coral reef, and has throughout most of its length a decided seaward dip. At the southern end of its contact with the beach, however, the dip is reversed and the bedding looks very much as if it had been formed by sand washed over and behind a low beach or spit. The rock is in some places rather soft, in others it is quite hard and rings when struck with the hammer. It contains many shells of living forms of mollusks, especially *mariscos*, and also calcareous Algae.

Certain features about the southern end of these reefs are interesting in connection with the coast history.

There is here a mangrove swamp being encroached upon by the sea, — a somewhat unusual process. The swamp, as will be seen from the sketch, was formerly protected by the reefs, but the sea has gradually broken down this barrier and, encroaching upon the shore about its southwest end, has attacked the mangroves. In the embayment south of the existing swamp and reefs the shallow bay contains a great many dead stumps of mangrove trees still standing in place.

The stone reefs of the Pratagý, Alagôas. — The Rio Pratagý is a small stream, not more than sixty metres wide, entering the ocean eleven or twelve kilometres north of Maceio. Where this stream enters, a small sandstone reef lies square across its mouth.

Both north and south of the Pratagý and within a short distance are other reefs or fragments of stone reefs that may be considered as parts of the one in front of the river's mouth.

The chief features of the topography of most of this part of the coast consist of a flat-topped plateau of Tertiary sediments rising abruptly from near sea-level to an elevation of from fifty to a hundred metres. The margin of this plateau is cut across here and there by streams coming down from the interior and forming, especially near the coast, rather steep-sided, flat-bottomed valleys.

It is through one of these valleys that the Rio Pratagý enters the sea. The narrow strip between the mouth of the river and the foot of the Tertiary escarpment is low, flat, and mostly sandy, but near the stream covered with mangrove swamps. Just back of the beach and parallel with it is a somewhat higher bank of sand, apparently blown up from the shore.

The first or most northern of the Pratagý reefs begins on or near the beach one kilometre northeast of the mouth of the river. It is here only fragmentary, — one large piece after another, but lying always in a line, a little way out from the high-water beach and just covered at high tide. This reef runs into the beach four hundred metres north of the river. It has a decided dip to seaward.

Following along the beach a hundred metres or so from the southern end of this reef, one comes up behind a second stone reef that stands out in the water some seventy-five or one hundred metres from the beach.

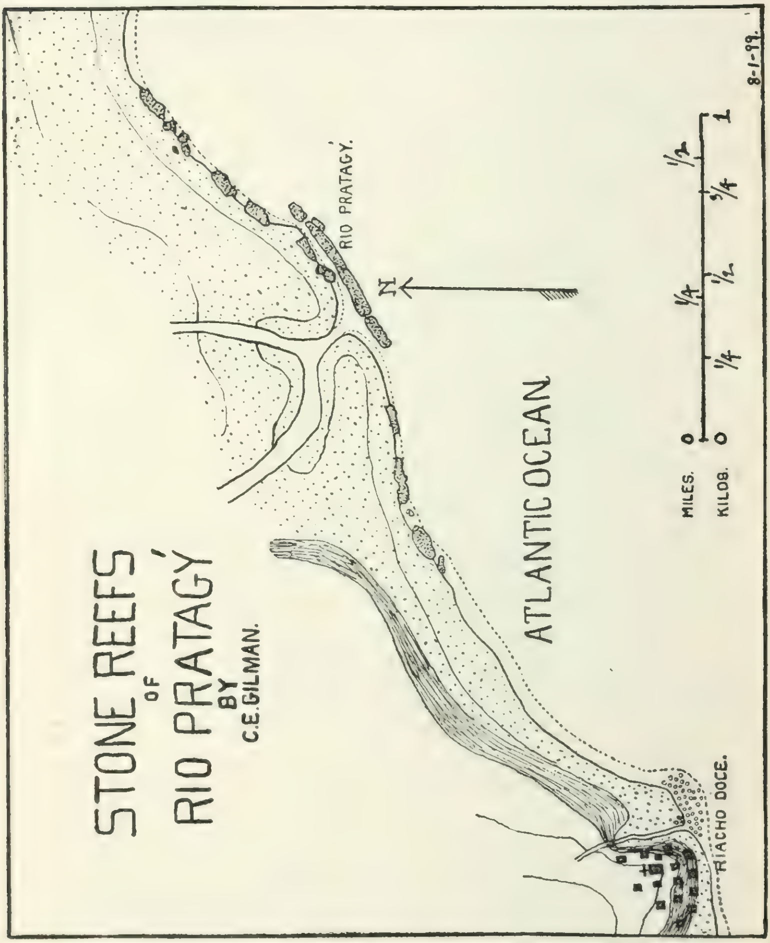
STONE REEFS
OF
RIO PRATAGY'
BY
C.E.GILMAN.
RIO PRATAGY.
N
ATLANTIC OCEAN
MILES. 0 1/4 1/2
KILOS. 0 1/4 1/2 3/4 1
RIACHO DOCE.
8-1-99.

Fig. 59.

Just around the turn of the shore is a third reef, — this one upon the beach. It dips seaward beneath the outer reef, which is here only about forty metres away from it. The size and position of this shore reef are shown on the accompanying map.

The outer reef is the largest, or rather the longest and most compact of the three at this place. It is the Pratagý reef, properly speaking, and lies across the mouth of the river, which flows north and south round both ends of it. It has a width varying between eight and twenty metres.

The rocks of these reefs are quite hard and compact, and of a light-brown color.

One hundred and seventy metres south of the Pratagý reef is another one of similar materials upon the beach. This one is about four hundred metres long and seems to be a part of the southward continuation of the inner or beach reef exposed just north of the mouth of the river.

The rock of this particular beach reef has a decided seaward dip, but in addition the top of the reef is worn off so that the upper surface itself has a seaward slope.

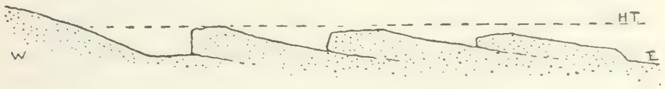

Fig. 60. Section of the Rio Pratagý sandstone reef.

This characteristic has been observed in several other of the rock reefs of the coast.

It is noticeable that these Pratagý reefs are not straight.

Outside of the outer stone reef are two other parallel sets of reefs. These reefs were not examined, but from their general appearance I judge them to be coral reefs. The most distant one of these appears to be about one kilometre out from the beach and approximately parallel to it.

The stone reefs of Bahia. — I have visited the stone reefs of Bahia several times, especially those at and near the lighthouse at the entrance to the bay, but I have not examined their full extent along the coast to the east of the lighthouse. As is well shown in the accompanying illustration of these reef-rocks, the blocks about the lighthouse have the appearance of having been undermined and broken into great angular slabs.

The Bahia reef is not exposed in a long beach-like line, as are most of the other sandstone reefs. Here there has been no stream entering the ocean from behind a bar, but the horizontal sand rock has been exposed by the encroachment of the sea upon accompanying beds. The reef appears to rest upon the edges of crystalline rocks.

The reef rock contains shells of marine mollusks now living along this coast, and Capanema[1] mentions seeing pieces of pottery imbedded in it.

The rock has been extensively quarried for flagging and for building purposes.

When I revisited the reef at this place in August, 1899, I found west of the lighthouse only one big slab of the reef rock. This slab is 5 × 2.1 × 0.5 metres. It lies loose upon the projecting points of the crystalline rocks of the beach as if it had been tossed there by the waves.

There must have been a beach reef at this place formerly, but it has now all been removed by man and the surf save this one slab and a few isolated patches of heavy conglomerates here and there among the ragged points of the crystalline rocks beneath them.

Among these conglomerates several fragments of bones were noted.

The following description of the Rio Vermelho reef, which I did not examine, is taken from Hartt:[2] "The reef at Rio Vermelho illustrates very well the general character of these consolidated beaches. It is composed of layers of calcareous sandstone and conglomerate, often somewhat irregular, dipping seaward, the dip being only a few degrees, or about that of an ordinary sand beach. The height of the reef is very uniform. In the finished and isolated reefs, as that of Pernambuco and the one under consideration, the recent rise of the land has brought this level somewhat above that of the sea. The solidified portion is seen to be but a sheet of varying thickness lying on the surface of the beach. On the inner side it is quite thin, and from the action of water behind it is undermined and broken off, until, at last, it forms a low perpendicular wall, undermined below and sometimes projecting several feet. Usually this side of the reef is flanked by a slope of sand or mud, and sometimes by large oblong blocks of sandstone. (See cut on p. 109.) The surface of the reef is, broadly speaking, horizontal, but it is marked by longitudinal ridges and much worn away, sometimes honeycombed and exceedingly rough with large, shallow or deep irregular pools of water, the homes of several species of corals, etc. The whole mass is divided by joints into great blocks. On the seaward edge the reef is often worn away by the waves and undermined, presenting always a perpendicular wall to the sea. The upper bed almost always projects a little, and the great blocks broken from it lie in front, which afford some protection to the reef. One often finds a depth of twelve to fifteen feet or more at low tide along this side of the reef. In most cases corals grow on the faces of these reefs below low water."

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[1] Guilherme S. de Capanema. Trabalhos da Commissão Scientifica de Exploração. Introducção. I. CXXXVII.

[2] C. F. Hartt, Geology and physical geography of Brazil, p. 344–345.

The stone reef at Santa Cruz. — Santa Cruz, in the State of Bahia, is a small town about two hundred and seventy kilometres south of the city of Bahia. It stands at the mouth and on the south side of the Rio da Santa Cruz, which river enters the Bahia de Cabral from behind and around the north end of a stone reef.

The general topography of the region about Santa Cruz is worthy of special note. There is a striking resemblance between it and the topography of Porto Seguro.

The flat-topped hills with an elevation of about fifty metres here come down to the shores. The plateau is cut across at this place by the Santa Cruz river. The valley, however, instead of being v-shaped, is steep only at the widely separated margins, while the floor of the valley is broad and flat. The hills at the town of Santa Cruz and on which the church stands are so steep on the northwest side that they are nearly perpendicular at several places. Low mangrove swamps are visible about the mouth of the river and follow up this stream for many kilometres, but it is to be noted that there is both near the mouth of the stream and further up the valley much land standing at an elevation of about three metres above tide. This is flat land, however. The reef extends right across the mouth of this valley, but stands a little way out from the hills. The river strikes the reef near its southern end, bends northward, and enters the sea around the north end of the reef. The south end of the reef laps back against the beach opposite the town. At its north end it is double, and as it breaks down isolated rocks continue for a few hundred metres beyond the end of the solid rock. At low tide this reef appears to stand about two metres out of water.

To the landward of the reef is a long line of mangrove swamps, so that unlike most of such reefs this one is not much undercut by the river that flows from behind it. It has a large break at one point.

I saw but little of the Santa Cruz reef and therefore give Hartt's description of it.[1] He says that it begins "on the shore just to the south of the village, continues in the trend of the beach, which is north a few degrees east, with an occasional break for a distance of about two miles, the river flowing behind it and escaping around its northern extremity. At low water the breakers show that the reef is continued under water with the same general trend northward, tying in with a reef which, beginning at a point about a mile north of the river-mouth, fringes the

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[1] Geology and physical geography of Brazil, p. 232–234.

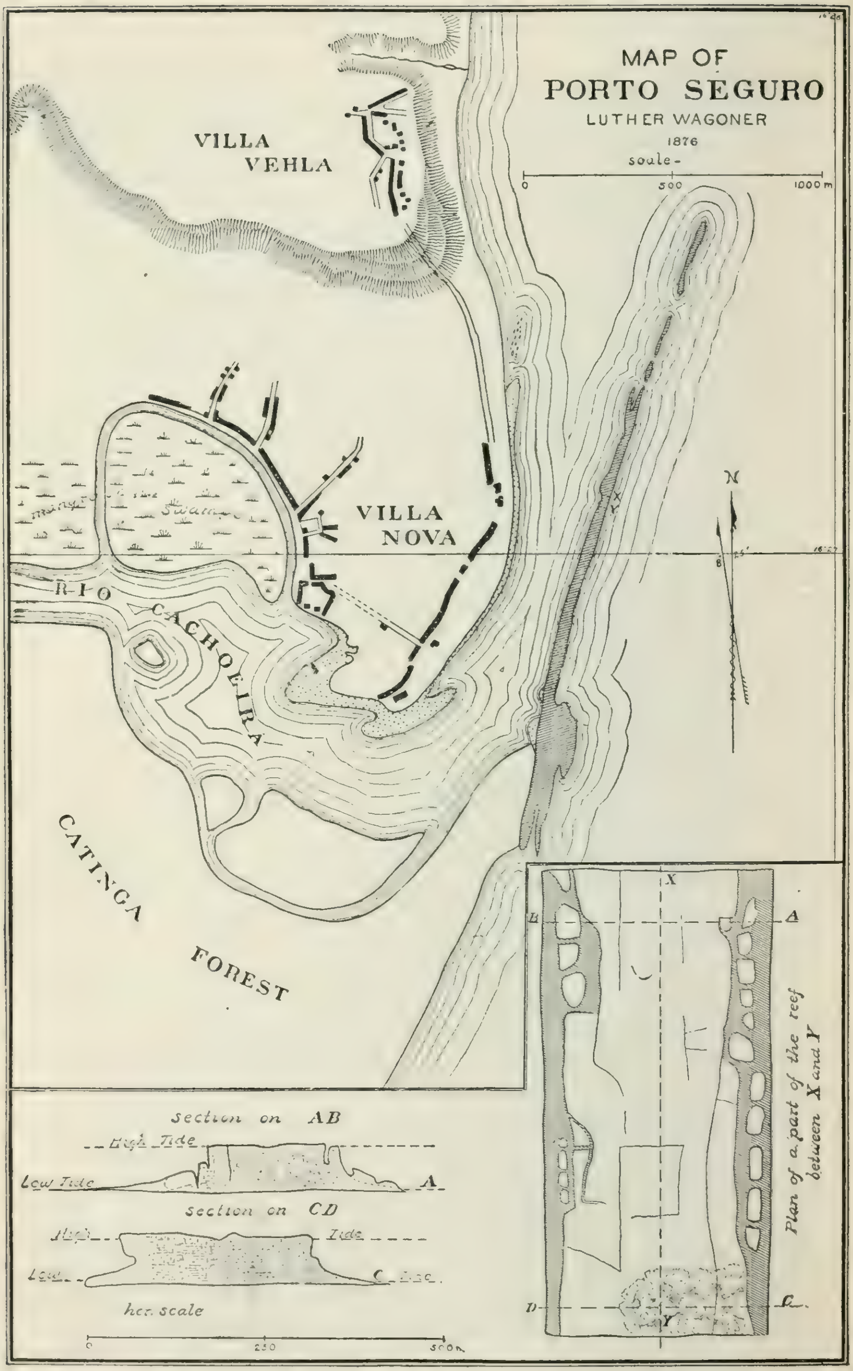
MAP OF
PORTO SEGURO
LUTHER WAGONER
1876
scale
0
500
1000 m
VILLA VEHLA
VILLA NOVA
mangrove swamp
RIO CACHOEIRA
CATINGA FOREST
N
section on AB
High Tide
Low Tide
A
section on CD
High Tide
Low Tide
C
hor. scale
0
250
500 m
X
Y
A
B
C
D
Plan of a part of the reef between X and Y

FIG. 61.

beach for more than half a mile. . . . In front of the town the reef clings to the shore, though there is a channel behind it filled at high water. The reef is much shattered, and great blocks lie tumbled about in confusion, broken from it by the waves. . . . At the extremity the reef is double, the remains of an old reef being visible on the outer side."

The stone reef of Porto Seguro.[1] — The Porto Seguro reef, like so many other of the stone reefs, lies across the mouth of a valley through which a river — in this case the Buranhaem or Cachoeira — enters the sea. North of this valley the coast hills, from forty to fifty metres in height, are close to the beach, but here and there are cut at right angles by narrow valleys. These hills with their flat tops come close to the valley of the Cachoeira, where they are cut down abruptly and left with an almost wall-like face standing at an angle of forty-five degrees or more.

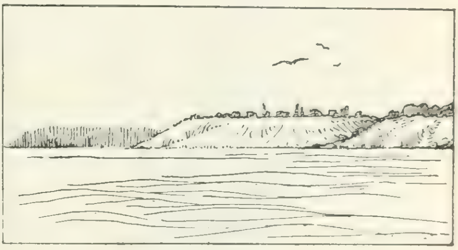

FIG. 62. Porto Seguro from the sea.

In the accompanying sketch (Fig. 62) the profile of the hills is seen where the face of the hill intersects the water horizon. About half a kilometre north of the upper city a narrow valley cutting across these hills has the outline shown in Figure 63.

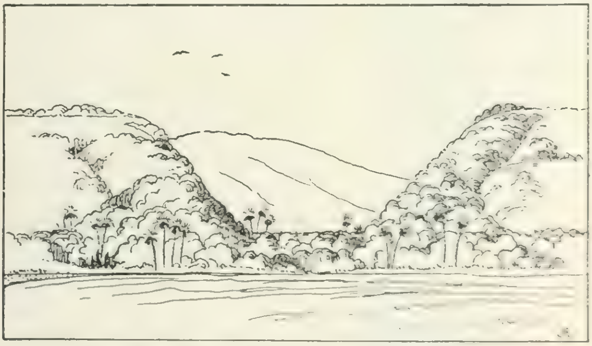

FIG. 63. Valley north of Porto Seguro.

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[1] The map of Porto Seguro and its reef herewith is from a survey made in 1876 by Luther Wagoner, member of the Commissão Geologica do Brazil. It has not been published before.

On the brow of this bluff stands the old town or upper city of Porto Seguro. The view from the edge of the plateau is remarkably fine, and throws much light upon the geographic history of the region. The accompanying sketch was made from the southwestern edge of the plateau in the outskirts of the old town. It was made so late in the day, however, that the details of the hills on the south side of the valley could not be seen. South of the valley these same steep-faced hills continue down the coast. The valley of the Rio Cachoeira is flat-bottomed, here sandy and there covered by mangues that extend back and up the smaller channels from the margin of the main stream like fingers from a hand. This flat valley, about its lower end at least, is less than one metre above the highest tides. On the south side of the river is a caatinga forest where the land is four metres above mean tide (Wagoner).

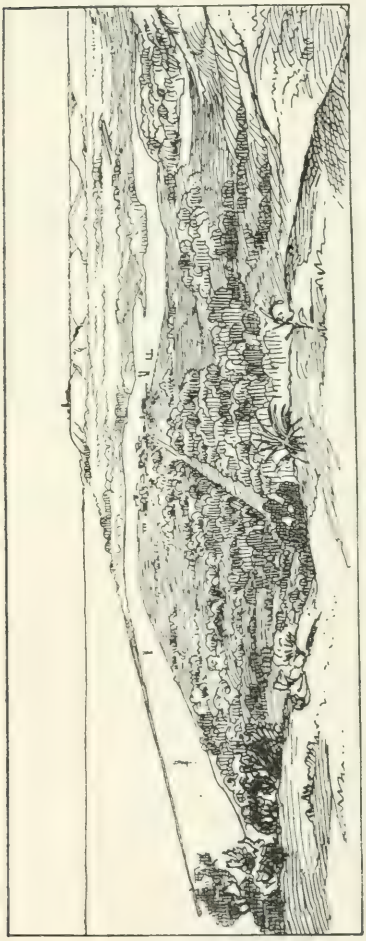

Fig. 64. The region about the mouth of Rio Buranhaem or Cachoeira. From a sketch made at the edge of the plateau at Porto Seguro.

The Porto Seguro reef has its southern end joined to the land and lies square across the mouth of the valley and of the Cachoeira River, which it deflects northward. The main unbroken reef is one thousand six hundred metres long, but beyond this to the north and lying in the line of the reef are four separate pieces which add six hundred metres more to its length. It varies in width from one hundred and thirty-five metres near its southern extremity to thirty metres in the narrowest part of the main reef; throughout the greater part of its length it averages thirty-five metres. At high tide the water breaks over it the entire length, but it is more effective as a breakwater than the Pernambuco reef. Its general effectiveness is due to the coral reef that lies outside, however, and greatly reduces the force of the surf that reaches it. At its southern end it is split in two. South of this end and in a general line of the main reef are five or six isolated rocks that are probably remnants of the reef in that direction. North of the north end of the reef there is no flat land on the beach, the cliffs coming close up to the water. There are no rocks on the beach as shown on the hydrographic charts.

The reef has the appearance of having been nearly everywhere more or less cracked and these cracks filled with sand which is now hard like the rest of the rock. In places the cracks have been washed open to a depth of more than half a metre. The cracks run in every direction, but the greater part of them are parallel with the reef. Along the sides blocks from three to six metres long and from one to four metres across have broken away from the main reefs on both sides and have sunk into the sand and mud next to the reef. In some places the reef rock overhangs on the landward side where it seems to be undercut by the stream or outflowing tide.

North of the river the old town of Porto Seguro stands upon a plateau forty-five metres high, and for the most part covered with forest.

The following description of this reef is given by Hartt, who examined it in 1865:[1] "The rock is obliquely laminated as in a sand beach, the lamina dipping seawards at a small angle. It is composed of rather fine sand, with occasional small pebbles, compactly held together by a calcareous cement. It contains an abundance of recent shells, Venus, Cerithium, Chama, etc., such as now live on the sea beaches of the vicinity."

There is, however, a marked difference between the rock of this reef and that of the others. The sand is much whiter and, on the average, coarser. Many of the pebbles are as large as pigeon's eggs, and the fossil shells are moderately abundant. In one block I found a piece of the coral *Porites* embedded in the reef rock. In places the reef rock is exceedingly hard and breaks through the quartz grains with an almost glassy fracture.

My general impression of the Porto Seguro reef is that it is one of the weakest of the Brazilian stone reefs. It is an important one because it protects the port in the great Cabral Bay already partly protected by the great coral reefs outside.

Notes upon little-known stone reefs. — The preceding detailed descriptions of individual stone reefs contain all the notes made upon the reefs thus far examined. These, however, are not the only stone reefs of the northeast coast of Brazil. There still remain several that have not been examined and about which very little is known. Under the circumstances it seems best to give that little here, and to mention the places at which stone reefs are reported, whether anything else than their existence is known about them.

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[1] Geology and physical geography of Brazil, p. 229.

Some important reefs may have been omitted from this list, but it is doubtful whether facts to change any of the conclusions reached would have been obtained by an examination of the reefs not seen.

In mentioning "reported" reefs, proper allowance has been made, in so far as possible, for the general disposition to lump all the reefs of this coast together. To navigators all reefs are pretty much alike, so much so that the Pernambuco stone reef, the best-known one of Brazil, is often put down in sailing directions for the south Atlantic as a coral reef. The confusion is further increased by the customary addition that this same reef borders the whole Brazilian coast. With such reports as these we try to have nothing to do.

On my trip from Pernambuco to Natal in June, 1899, for the purpose of studying the reefs, it was not possible to examine all the places that it was desirable to examine because of the inaccessibility of the shores for the *barcaça* in which the trip was made. This difficulty was evaded in some instances by following the beaches on foot, but this was not always convenient, and necessarily delayed the work.

Guajú. — There is a line of reefs beginning three or four kilometres south of Pavuna (S. lat. 6° 32′), in the State of Parahyba, and stretching across the low lands in front of Rio Guajú. Rio Guajú enters the sea through a flat valley between rather steep-faced hills. This reef was not examined, but its configuration and the nature of the country back of it lead me to believe it to be a sandstone reef.

Sargí. — Across the mouth of another small stream north of the Guajú, probably the Sargí, is a reef which, seen from the ocean, has every appearance of being of sandstone.

João dos Santos. — At João dos Santos a stream enters the ocean and reefs lie across the mouth of it and extend two or three kilometres to the south. The geography and general appearance lead me to believe it to be of sandstone.

Tibáu. — At Tibáu (S. lat. 6° 11′) a small stream enters the ocean from behind a short reef that appears to be of recent sandstone.

Camorupim. — About 2.5 kilometres north of Tibáu begins a stone reef which continues northward for several kilometres very close to and in places on the beach itself. This reef is broken at the mouth of Rio Camorupim. I was told by persons living near Rio Pirangý that this reef continues to the north of the Camorupim nearly to Tabatinga. I was also shown blocks of stone said to have been taken from this reef. The rock is the recent reef sandstone containing the characteristic fossils.

São Miguel, Alagôas. — Pedro Antonio dos Santos of Porto de Pedras, State of Alagôas, is one of the few men I have met who has distinguished between the coral and the sandstone reefs of this coast. He informs me that there is a reef of sandstone across the mouth of the Rio de São Miguel twenty-four kilometres south of Maceio.

Ilheos. — At Ilheos, State of Bahia, is a reef on the beach south of the Morro de Pernambuco which appears to be of sandstone. It laps against the crystalline rocks of the hill at its northern end, and extends down the beach for a kilometre or more, lying in front of the low lands of Pontal and across the mouth of the river. (See illustration on p. 154.)

Miscellaneous localities. — On the trip down the beach from Pernambuco to Maceio at several places besides those already mentioned the beach sands were found more or less lithified. The most of these are here specified.

At Candeias, sixteen kilometres south of the Pernambuco lighthouse, there is a soft sandstone exposed on the beach for about three hundred metres. It is evenly bedded, very calcareous, and so soft that the hammer sinks in it. Worm or molluscan borings made in these sands while soft are enough harder than the rest of the material to be left, on being washed by the surf, looking like roots penetrating the beds. These soft rocks are all within reach of the highest tides.

A little further south at the *Barra das Jangadas*, where the stream enters the sea, a soft calcareous sandstone is exposed by the encroachment of the stream on its northern bank. A kilometre further up this stream on its north bank the light brown sands are partly hardened. These beds also have the molluscan tubes crossing them.

Pedras Pretas is a small cape just north of Cape Santo Agostinho and thirty kilometres south of Pernambuco. In the curve of the shore north of the point there is a soft sandstone on the beach. It stands half a metre and less above the sands, is from five to ten metres wide, and three hundred metres long.

It dips with the beach 5°, 7°, and 8°. The sandstone is not coarse, and it contains but few shells; there are some red iron cemented

Tertiary (?) pebbles embodied in it. The surface is partly flat and partly etched and rounded.

The Rio Maracabýpe enters the sea twenty-three kilometres south of the Cape Santo Agostinho lighthouse. Up this stream half a kilometre above its mouth sandstone like that of the stone reefs is exposed at low tide on the north side. It contains many fragments of calcareous Algae.

South of the Rio da Cruz and between it and the Ponta do São José there are many exposures of soft calcareous sandstone on the beach. It contains many coral fragments and broken calcareous Algae.

On the beach south of São José point there is much of this partly hardened rock containing many shells.

Four hundred metres upstream from the mouth of the Rio Maragogý (S. lat. 9° 3′) on its south side, and about sixty metres from the base of the Tertiary (?) hills to the west, is a soft sandstone containing recent shells.

Rio Salgado, the next small stream south of the Maragogý, has a small reef of soft sandstone across its mouth. It is a rather patchy one, however, and is from one hundred to one hundred and fifty metres out from the beach. Part of this reef lies on the point just north of and opposite São Bento. These reef patches are here covered with Serpulae, barnacles, and oysters. Similar rock is exposed within the mouth of the Rio Salgado. This looks as if it extended under the plain on which São Bento stands. It contains marine shells.

One and a half kilometres south of the Barreira do Boqueirão (S. lat. 9° 9′) low tide exposes a sandstone reef. It bears N. 36° E. (magnetic) and dips gently seaward. The end examined on shore is only one of the fragments of this reef; other fragments lie in a line more than halfway across the embayment.

Between São Miguel and Rio Camarigibe (S. lat. 9° 19′) at a place called Marceneiro the tides have undercut the bank and exposed soft calcareous sandstones from one to two metres thick. The rock is so pure that it is burned for lime. South of Marceneiro this bank of soft calcareous sandstone continues to have a height of from one to 2.5 metres.

At Riacho Doce and between that place and Garça Torta in the State of Alagôas are several fragments of stone reefs exposed on the beach. At one place there are blocks from three to eight metres long and a metre thick lying on top of a coral reef and granite boulders. At another place a sandstone reef sixty metres long rests on a coral reef, and at still another there is an exposure of one hundred metres of the sand reef alone.

The following localities I have not seen, but they are mentioned by Hartt:[1] A bit of consolidated beach of "quartz sand cemented by carbonate of lime" just south of Guaraparý, State of Espirito Santo (p. 62).

At Barra Secca, about fifty kilometres north of the mouth of Rio Doce, there is a similar sandstone uncovered at low tide (p. 107).

At As Pedras, Espirito Santo, there is a similar sandstone on the beach (p. 114). "The sandstone is exceedingly hard. Two sets of joints — one parallel with the beach line, the other at right angles to it — divide it into great blocks, which, in those spots where they have been undermined by the surf, lie upset and in confusion along the edge of the reef. Along these joints the rock is harder than between them, so that when the surface of a block is exposed to the action of the sea, the edges wear less rapidly than the middle, and the cracks seen on a worn surface are oftentimes bordered by narrow ridges. . . . The waves beat terribly against the reef, and it is badly broken up."

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[1] Ch. Fred Hartt, Geology and physical geography of Brazil. Boston, 1870.

IV.

Conclusions regarding the Forms and Structure of the Stone Reefs.

I. THE FORMS OF THE STONE REEFS.

It is often stated by writers on the stone reefs of Brazil that they are perfectly straight. Liais himself, who saw those at and immediately south of Pernambuco, says, "*jamais la récif ne se courbe.*" To be very exact, this is hardly true.

That the reefs do curve somewhat is shown by the illustrations and maps given herewith. These curves, however, are always gentle, and it is only a matter of strict interpretation of language to say that they are not straight.

Inasmuch as the reefs are only modified sand beaches, in order to understand their forms we must comprehend the forms of sea-beaches generally, and also to some extent the causes of such forms as we have along the Brazilian coast.

Sand beaches, or beaches of construction, are built up with the materials supplied by their own coast-lines: cut from headlands, washed down from the land by streams, or washed ashore by storm waves that throw them up from the shallow sea off-shore. The idea that has been put forward that the sands of the northeast coast of Brazil may have been brought from the west coast of Africa may safely be set aside as quite out of the question.

Straight beaches may be produced in two ways: —

I. By the elevation of a sea bottom, or the depression of a land surface that is so smooth that the new beach line, after elevation or depression, is unbroken by surface irregularities.

II. By the natural process of straightening an originally irregular, indented, or broken shore-line by the cutting down of the headlands and the choking up of embayments.

In the latter case the beach is crooked at first and its straightness comes only with age.

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[1] *L'Espace Céleste*, p. 546.

Inasmuch as the beaches of which the reefs have been made have the appearance of being accumulations or accretions, we may set aside the probability of their having been formed by the elevation of a smooth sea bottom and deal with the methods by which straight beaches are produced from crooked ones.

They may be considered as originating in two ways, or by a single structural process, operating under two different conditions. These conditions may produce : —

First, *shore beaches,* — the accumulations along the margin between the mainland and the main body of water.

Second, *off-shore beaches,* or the beaches developed as spits, bars, or barrier beaches lying parallel with the main coast-line.

The shore beach. — The form of a shore-line is determined (1) by wave action, (2) by the resistance of the shore rocks to marine encroachment, and (3) by the direction of inshore currents. On a coast having alternate bays or estuaries and headlands, we inevitably have alternate currents and eddies next to the shore. The waves and currents attack the headlands and throw the coarse materials cut from them into the more quiet waters of the bays, where they sink to the bottom. If, however, the prevailing winds drive the waves squarely against the shores, the silts are thrown back against the inner margins of the bays, and the beaches are built outwards by a continuous and approximately uniform process of accretion. The tendency along such shores is, therefore, for the beach gradually to become straight by the cutting down of the headlands and the outbuilding of the concave beaches. The early beaches must, therefore, have been crooked, or more so, at least, than the later ones. The temporary shiftings of the currents, either of the streams or of the sea, have probably played an important part in determining the forms and locations of the beaches and of the stone reefs.

It is evident, however, that the straight beaches are comparatively mature ones, for it is only after the agencies mentioned have been in operation for a long time that the broken line of the early history of the shore becomes a straight one.[1]

The off-shore beach. — Off-shore beaches might be divided into those originating as spits and those built up from the bottom as bars not connected at the surface with the land. No sharp line can be drawn between them, however. If the near-shore currents or the prevailing winds are parallel to the coast, or if they strike the coast at a low angle, spits are built across the mouths of bays and estuaries.

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[1] Lapparent says, "the work of the sea on flat coasts is essentially constructive." (Traité de géologie, 2me ed. 171.) This statement, however, might be turned about and be equally true; that is, a newly constructed sea-coast is essentially flat.

The materials for such spits may be the débris derived from the headlands, or it may be brought down from the land by streams, or it may be swept along the coast for miles until it falls into the quieter waters behind or to the lee of the points where alone such spits can be formed. When the sea is shallow the coarser materials from the bottom — the continental shelf or shoulder — may be thrown upon the shore and swept along to help form these spits. Sometimes the spits entirely shut off the sea from the water of the bays, and a series of lagoons or salt lakes is formed along the shore. In a rainy region these lakes will become brackish, eventually fresh, and finally they will be silted up and form marshes and, in the end, dry land. The lakes of the coast of Alagôas are now passing through these stages, and at no distant day, speaking geologically, they will become extinct as lakes.

Along certain coasts and about the mouths of large streams we have off-shore beaches formed in a somewhat different manner, though they usually merge into spits. These are sometimes called "barrier beaches."[1] They are long, slender bars that barely rise above the surface of the water. In some cases they are many miles, or even hundreds of miles, in length. Such bars, beaches, or barriers are built up from the bottom.

The explanation of barrier beaches was pointed out nearly two hundred years ago by a French engineer as "The limit between the embankments formed by storms at sea and those derived from fluviatile deposits."[2] They are a part of the process of the outbuilding of terrigenous agencies.

It is worthy of note that wherever these off-shore beaches exist the range of the tides is not great, and the currents set pretty constantly in one direction, and that in the submarine topography there is a rather sudden dropping off from a shallow shelf near shore to deep waters beyond.

The straightness of such beaches is likewise noteworthy. Gannett says that "they are very straight, running for hundreds of miles with but slight deflections from a straight line."[3]

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[1] N. S. Shaler, The physiography of the United States, p. 151, N. Y., 1897.

H. Gannett, Physiographic types. Typographic atlas of the United States, Folio I., U. S. Geol. Surv. Washington, 1898.

[2] Quoted from Forfait, by Élie de Beaumont, Leçons de géologie pratique, I., p. 326.

[3] Henry Gannett, Topographic atlas of the United States. Physiographic types, p. 4. Washington, 1898.

There are excellent illustrations of such spits and barrier islands along the coast of New Jersey. Island Beach is twenty miles long from Bay Head to Barnegat Inlet, and is almost perfectly straight. Between this bar and the shore is a broad sound, Barnegat Bay, which will eventually silt up if the encroachment of the sea does not cut the beach away.[1]

Long Beach, from Barnegat City to Great Bay, is twenty-two miles long, nearly straight, and is nowhere naturally connected with the mainland. The beach at Atlantic City, New Jersey, is nine miles long, with a marsh from three to six miles wide between it and the mainland.[2]

Sandy Hook, at the entrance of New York harbor, is now a spit thirteen miles long, measured from Long Branch to the point of the hook. Professor Cook points out that the spit formerly[3] joined the Navesink Highlands, while the Navesink River entered the Atlantic south of the highlands. Within recent times the beach has been thrown up outside and half a mile away, and the spit has been made into a continuous beach from Sandy Hook to Long Branch.[4]

Similar barrier beaches border the coasts of North Carolina, Texas, Mexico, Yucatan, and Rio Grande do Sul in Brazil; in the same category belong the *lidi*, or long bars, about the mouth of the Po; others about the mouths of the Nile and the Rhone; the Haffs of the south shores of the Baltic Sea; the spits of the Sea of Azov; the long bars off Lake Chilka, on the east coast of Hindostan, etc. In many instances these beaches are phases of the seaward extension of deltas; that is, the materials have been brought down from the land by the streams behind them. Many such beaches have lakes shut in behind them.

Another convenient illustration in Brazil itself is the low beach between Cape Frio and Itaipú peak near Rio de Janeiro. Here the low, flat, sandy beach lies in front of a series of lakes shut in between the sea and the lofty mountains north of them.

The rate of growth of a beach-line depends partly upon the frequency and force of storms along the coast, partly upon the nature of the rocks of the shores, partly upon the slope of the land, and hence upon the rate of stream cutting, and partly upon off-shore submarine topography.

Application to the Brazilian stone reefs. — The straightness of the Brazilian reefs shows that they are the remains either of off-shore (or barrier) beaches or of old shore beaches. If they were originally barrier beaches we should expect to find low, flat, newly made land lying between them and the high ground of *terra firma*. If they were originally shore beaches we might expect to find them resting unconformably against the older rocks of the headlands. This latter characteristic, however, is not necessarily confined to in-shore beaches, but may belong to both barriers and to spits formed well off the main shore.

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[1] Vicinity of Barnegat Bay. Atlas sheet 13. Geol. Surv. of N. J., 1889.

[2] Topographic map of Egg Harbor and vicinity. Atlas Sheet 16. Geol. Surv. of N. J., 1889.

[3] Sandy Hook topographic sheet. U. S. Geol. Survey.

[4] Ann. Rep. State Geologist of N. J., 1885, p. 77–78.

The constant blowing of the winds on shore and the narrowness of the continental shoulder have favored the near-shore formation of barrier beaches along the Brazilian coast.

At Cape Santo Agostinho the reef rock laps back against the granite rocks of that headland. Both north and south of the cape the elevated country falls away from the shore, leaving the region near the shore flat; but in no case is this flat belt more than two or three miles wide, save where streams flow in through open valleys. North of the cape the coast is low and flat all the way to Olinda, where a headland again reaches the sea. The stone reefs off the mouth of Rio Goyanna are well out from the land. The Mamanguape reef approaches a Tertiary (?) hill only at its southern end; the Natal reefs do the same. The Serinhaem reefs stand well out from the hills, though one of them is now a beach reef. At Bahia the stone reefs were formed against steep banks. At Porto Seguro the reef is half a mile from the hill on which Villa Velha stands, while south of these the high land swings abruptly inland, leaving a low, flat region to the landward of the reef. At Parahyba do Norte the land of the peninsula of Ponta do Matto, where the recent rock is found, is all low.

There are no lakes at present immediately behind the stone reefs, though such lakes must have existed formerly. Lagôa de Almada, in the State of Bahia, is a fresh-water lake, believed by Spix and Martius to have been formerly an arm of the sea. Stone reef rocks are said to be found in the vicinity of this lake, but no mention is made of the geographic relations of these rocks to the lake.[1] There are no barrier beaches along the northeast coast of Brazil now except those of coral.

It is a noticeable characteristic of the shore forms behind the stone reefs, that wherever there is a break in the reef, the new shore-line falls away, forming an indentation like that just north of Gaibú (see p. 70).

Structure of the stone reefs. — The structure here considered relates only to gross structure, — the bedding and the relation of the beds to each other. The composition is treated under the head of "Consolidation" in Part VI.

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[1] J. B. von Spix und C. F. P. von Martius, Reise in Brasilien, II., p. 684–685. München, 1828.

The structure of a stone reef in cross-section is well shown in the accompanying figure, which was first published by Hartt in 1870.

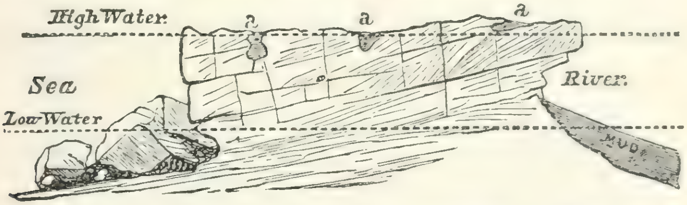

FIG. 65. Theoretic section across a stone reef. — Hartt.

The same structure is shown in Wagoner's section of the Porto Seguro reef. (See p. 96.)

In the undisturbed rocks the dip is almost invariably seaward, and the angles are the low angles common to beach sands. I have often measured the slopes of the beaches, and in a few instances I have been able to measure the dips of the reef rocks. At Piedade, a village on the coast a few kilometres south of Pernambuco, the rocks of the stone reef dip at angles varying between 4½ and 6½ degrees; the beach sands at the same place dip at angles varying between four and five degrees. At Venda Grande, just south of Piedade, the beach has a slope from four to five degrees. I have measured sand slopes as high as 37°, but these were cases of false bedding. The steepest beach noted on which the waves played was at the mouth of Rio Sapucahý, where it had a slope of 11°.

At Pedras Pretas, the small cape just north of Cabo Santo Agostinho, a small stone reef has dips varying between five and eight degrees. The beach sands have similar dips. The stone reef of Pratagý shows its seaward dip well, but no angles were measured. Some of the photographs of the Mamanguape reef also show the seaward dip of the rocks. Occasionally one sees strongly marked false bedding in the reef rocks. Cases of the kind have been noted on the Mamanguape reef. At Rio Grande do Norte the reef, as seen from the lighthouse on the reef, shows the beach structure fairly well.

Mention should be made here of the statements of Liais that the reef rocks are sometimes vertical. As pointed out in Part V., no cases are known to the writer in which the reef rocks are vertical or have very high dips except where certain blocks have undermined and have tipped up on one side.

Considered in relation to underlying rocks, the structure of the stone reefs is best understood from the results obtained by the holes bored in the Pernambuco reef in 1874 by Sir John Hawkshaw. The following is the record of the deepest hole[1] put down.

RECORD OF BORING ON THE PERNAMBUCO REEF.

	METRES.
Reef rock, hard	2.95
White sand	1.22
Shells	1.10
Gray sand	0.65
Broken rock	1.27
Dark sand	2.10
Mottled clay	1.80
Yellow clay	0.70
Gray sand	3.00
White sand	2.20

Other holes put down in the reef show that the surface rock is underlain by sands, shells, and clays, but there is no regularity in the sequence of these materials.

Conclusions. — The stone reefs are nearly, but not quite, straight. The bedding of the materials dips seaward at the same angle as ordinary beach sands. The hard rock of the reef is only three or four metres thick. The underlying materials are sands, shells, and clays without regular sequence. The process of formation, the character, and the structure of the reefs show that they are ancient beaches hardened by lime carbonate, while their straightness shows that they are forms of a mature beach-line fixed and made permanent by the process of consolidation pointed out in Part VI., pp. 171–198.

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[1] Melhoramento dos portos do Brazil, p. 15. Rio de Janeiro, 1875.

V.

The Elevation and Depression of the Northeast Coast of Brazil.

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CHANGES OF THE REEFS WITHIN HISTORIC TIMES.

There are, perhaps, but few coasts of considerable length on which there are not evidences of both elevation and depression. Along the west coast of North America, for example, wave-cut terraces upon the slopes of the hills and mountains near the coast show that there have been several recent elevations of the land, while well-defined submerged valleys,[1] the distribution of the fish faunas in fresh-water streams, and the relations of fauna and flora of the islands off the coast to those of the mainland show that there have also been recent depressions.

Observations of others. — Humboldt and Darwin show that there has been a recent elevation of the northern end of the South American continent,[1] while the dendritic fjords and islands along the coast from Tierra del Fuego to south latitude 41° show that there has also been a comparatively recent depression in that region.[2] A late paper by Professor Gormaz of the University of Chile directs attention to the fact that while there are evidences of elevation along that coast, certain localities show equally satisfactory evidences of depressions, even within the historic period.[3]

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[1] George Davidson. The submerged valleys of the coast of California, U. S. A., and of Lower California, Mexico. Proc. Cal. Acad. Sci., 3rd ser., Vol. I., p. 71–103, and plates. San Francisco, June, 1897.

But the localities mentioned by these writers are far from the region with which we have to deal. The question with which we are chiefly concerned is whether there have been changes of level within historic or geologically recent times along the northeast coast of Brazil, and whether such changes, if they did occur, bear directly upon the existence and forms of the stone and coral reefs of that region.

We must also keep in mind the great length of the Brazilian coast-line, — about sixty-four hundred kilometres from the northern end at the mouth of the Oyapoc on the frontier of French Guyana (5° 10′ north lat.) to the frontier of Uruguay at the mouth of Rio do Chuy in south latitude 33° 45′. As in other parts of the world, where so long and so nearly straight a coast-line is concerned, the orographic movements over this distance have not necessarily been at the same rate or even in the same direction.

The evidence of a geologically recent elevation of the southern coast of Brazil is fairly satisfactory, while still further south in the Argentine Republic it is remarkably impressive, and considerable elevations are reported to have taken place even within the historic period. Many facts concerning the southern end of the continent are given by Darwin in his "Geological Observations," Chapters VIII. and IX.,[4] and by J. B. Hatcher in his paper upon the geology of southern Patagonia.[5] These facts show that the change of level affected the east coast for a distance of nineteen hundred kilometres, that the elevation has been greater toward the south and west, and that it diminished northeastward. In southern Patagonia[1] the elevation is given as four hundred feet (one hundred and twenty-two metres); in the La Plata region it has been one hundred feet (thirty metres). Darwin, however, does not maintain that the elevation of the Cordillera and that of the La Plata provinces took place at the same time.[2]

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[1] Darwin's Geological observations, Chap. IX.

[2] Professor Shaler notes, however, that the submarine cutting of ice may be responsible to some extent for the form in this case. Bull. Geol. Soc. Amer., 1894, VI., p. 162.

[3] Francisco Vidal Gormaz. Depressions and elevations of the southern archipelagoes of Chile. Scottish Geog. Mag., Jan., 1902, p. 14–24.

[4] Dr. Friedrich Gustav Hahn published at Leipzig in 1879 a paper upon the elevation and depression of coasts. (*Untersuchungen über das Aufsteigen und Sinken der Küsten*) — in which he gives a brief résumé of the evidence of the upheaval of the southern part of Brazil (pp. 93–97). This paper, however, in so far as it relates to the coast under consideration, contains only the facts given by other authorities.

[5] J. B. Hatcher. On the geology of southern Patagonia. Amer. Journn. Sci., Nov., 1897, CIV., p. 345–350.

Although Darwin's discussion refers chiefly to the La Plata region and to the country south and west of there, he mentions also evidences of the elevation of the coast of southern Brazil at Santos and near Cape Frio.[3] Barão de Capanema states that the city of Laguna in the State of Santa Catherina "stands upon a dark alluvial deposit densely packed with shells which have not been carried there, for I found oyster shells grown upon a granite cliff half a metre above the present level of the city and something more than two metres above the highest water-mark of the harbor."[4]

The evidences of the elevation of the coast near Rio de Janeiro consist of recent shells in sands now above tide, about the Bay of Rio; reported sea-urchin holes bored in the granite rocks at the base of the Pão d'Assucar and now above the reach of the tides; similar holes at Villa Velha; and marine erosion lines beyond the reach of tide-water at Victoria.[5] Herbert Smith mentions[6] one place where recent shells are found four metres above high tide on the Bay of Rio de Janeiro.

For the coast north of Espirito Santo but little evidence has been published showing changes of level. Some very general statements have been made and theories advanced, but the only specific evidence published on the subject consists of two papers by Richard Rathbun referring to the elevated beach at Porto Santo in the Bay of Bahia.

This leaves a long coast-line of whose vertical movements little or nothing is known. And it should be remembered that Victoria, where the evidences of changes are satisfactory, is four hundred and forty kilometres from the stone reef at Porto Seguro, the southernmost of the stone reefs, fourteen hundred and fifty kilometres from Pernambuco, and two thousand and ninety kilometres from the northernmost reef at Ceará.

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[1] Darwin's Geological Observations, p. 218.

[2] Geological Observations, ed. 2, p. 210–211.

[3] Geological Observations, p. 193.

[4] Mittheilungen aus Justus Perthes' Geogr. Anstalt von Dr. Petermann, 1874, p. 230.

[5] Ch. F. Hartt. Geology and physical geography of Brazil, p. 35, 71–73.

[6] H. H. Smith. Do Rio de Janeiro a Cuyabá. Notas de um Naturalista, p. 10–11. Rio, 1887.

Have there been changes within the historic period? — Several writers have expressed the opinion that the northeast coast of Brazil has been elevated recently. It is not always clear whether they mean "recently" in the historic or in the geologic sense. Capanema, however, speaks of a recession of the sea at one place at the rate of "ten fathoms in thirty years."[1]

This must necessarily be taken to mean an elevation during the present century.

The point at which this particular elevation is said to have occurred is Aquiraz in the State of Ceará, four leagues southeast of the city of Ceará and half a league from the coast. It is off the ordinary routes of travel, and as the writer has not visited the place and knows of no account of it by other observers, we can only judge it by what is known of other places on this coast.

Inasmuch as the sandstone reefs of northeast Brazil have attracted the attention of navigators and travellers since the earliest times, and as these reefs are of great importance to commerce, and inasmuch as any elevation or depression of the coast would immediately produce noticeable effects upon them, they afford an excellent means of judging as to whether or not any such changes of level have taken place since the discovery of Brazil.

It was to have been expected that so remarkable a natural phenomenon as the sandstone reefs of Brazil would arrest the attention of the early navigators. The oldest accounts we have of the reefs relate to those at Porto Seguro and at Pernambuco.

Pero Vaz de Caminha, one of the companions of Cabral, the discoverer of Brazil, was the first to make mention of the reefs, — the one at Porto Seguro, where Cabral landed in the year 1500. He merely mentions it, however, as a "reef having a very good and secure port inside of it."[2]

Pero Lopes de Souza was at Pernambuco in 1530; he mentions the reef at that place, the one near Cabo Sto. Agostinho, and one at

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[1] Trabalhos da Commissão Scientifica. I. Introducção, p. cxxxvii. Rio de Janeiro, 1865.

[2] Carta de Pedro Vaas de Caminha a El Rei D. Manoel. Collecção de noticias para a historia e geografia das nações ultramarinas que vivem nos dominios Portuguezes. Tom. IV., No. III., p. 180 a. Lisbôa, 1826.

Corografia Brazilica de Manoel Ayres de Cazal. I., p. 12–34. Rio de Janeiro, 1817.

Revista do Instituto Historico e Geographico do Brazil, 1877, XL., Pt. II., p. 13–37.

São Miguel on the coast of Alagôas, but he gives no description of them.[1]

Gabriel Soares de Souza, who lived in Brazil from 1570 to 1587, gives the earliest statements regarding the nature and extent of the reefs, though he makes no distinction between stone reefs and coral reefs. He notes, however, that the reef at Bahia was covered at high tide. There can be no doubt that he refers in this case to the sandstone reefs, for he says that the rock was used for building purposes in the city of Bahia, — a fact to which many of the old houses still bear witness. He also says that the reef rock is made of sand, and that it often contains oyster and other shells and pebbles.[2]

In 1625 Purchas speaks of the reefs at "Fernambuquo" as "Clifts as if it were made by Bricklayers, no higher in one place than in another, but all euen."[3]

The cuts of the Pernambuco reef reproduced by Varnhagem were first printed in 1630,[4] and appeared also in the original of Dapper's "Die Unbekante Neue Welt," in 1671.[5]

Joannes de Laet, one of the directors of the West India Company, who lived at Pernambuco from 1630 to 1636, published a map showing the reefs south of Cape Santo Agostinho and at Rio Grande do Norte.[6]

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[1] Diaro da Navegação da armada que foi a terra do Brazil em 1530 sob a capitania-mor de Martim Affonso de Souza. Escripto por seu irmão Pero Lopes de Souza, p. 14–15. Lisbôa, 1839.

[2] Noticia do Brazil. Published anonymously at Lisbon in 1825 by the Academia Real das Sciences as Vol. III., Pt. I., of the "Collecção de Noticias para a historia," etc.

Tratado descriptivo do Brazil em 1587. Por Gabriel Soares de Souza. Revista do Instituto Historico e Geographico do Brazil, 1851, XIV., p. 25, 27, 31, 33, 354.

[3] Purchas, his pilgrimes, in five bookes. Vol. IV., Chap. VII., p. 1238. London, 1625.

[4] Historia geral do Brazil. Pelo Visconde de Porto Seguro, 2a. ed., Vol. I. opp. p. 352 and 504. Rio de Janeiro (*circa* 1875).

[5] Dr. O. D(apper). Die Unbekante Neue Welt. Amsterdam, 1673. The original was written in Dutch by Arnoldus Montanus, and was published at Amsterdam in 1671. When translated into German, the book was ascribed to Dr. O. D. (Dr. O. Dapper) in whose collection it appeared. See bibliographical and historical essay on the Dutch books and pamphlets relating to New Netherland. By E. M. Asher. Amsterdam, 1854–67, p. 23; also Les Hollandais au Brésil. Par P. M. Netscher, p. xvii. La Haye, 1853.

[6] Historie ofte Iaerlijck Verhael van de Verrichtigen der Geoctroyeerde West Indische Compagnie Zedert haer Vegin tot het eynde van't jaer 1636. Leyden, 1644.

Elsewhere he gives a brief description of the stone reefs, states that they are exposed at low tide, and that they are broken here and there.[1]

William Piso, who lived at Pernambuco during the Dutch occupancy under Maurice of Nassau from 1637 to 1644, says of the reef at that place that "its height is such that it is rarely covered by the highest tide."[2]

Caspar Barlæus, the first edition of whose work was published in 1647, gives Piso's description of the reef, but he gives besides a plan of the reef and of the city of Pernambuco, and a view of the reef taken from the south end and looking toward the city and the northern end of the reef.[3] But Barlæus was never in Brazil, and his information was all at second hand, probably from Piso.

Pierre Moreau, who lived in Brazil two years, was at Pernambuco about 1648, and says of the reef that it is "as high as a pike or more, uncovered when the tide is out, but not otherwise because it is all covered."[4]

Other early references to the reefs will be found in the annotated bibliography forming part of this paper under the names of Dapper, Angelo, Nieuhof, Gioseppe de S. Teresa, Ayres de Cazal, and Koster.

These writers differ somewhat in regard to the height of the reefs, some of them stating that they are only uncovered at low tides, and others that they are rarely covered by the highest tides. These differences, however, are precisely the kind of differences of opinion one may find to this day in regard to the height of the reefs among people perfectly familiar with them. And it is not to be supposed that the old writers spoke with any unusual precision about this matter.

During the spring tides here and there points remain uncovered at high tide, especially if there be but a little wind. At some places, however, where the reef has been undermined, and huge blocks of stone have been tipped on end, these may not be covered even at the highest tides except by the surf dashing over them. There is such a block on the Rio Formoso reef, where it is popularly known as the "Pedra de Nossa Senhora." At ordinary high tide the reefs all along the coast appear for the most part as a line of breakers with black points of rock now exposed and now covered by the surf. Whether the waves break over the reef during neap tides depends much on the winds blowing on shore. At low tide these reefs almost invariably stand out like black walls surf-beaten on the seaward side.

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[1] Le Sieur Ien de Laet, d'Anvers. L'histoire du nouveau monde, p. 530, 533. Leyde, 1640.

[2] Gulielmi Pisonis — de Indae utriusque Re naturali et Medica, p. 6–7. Amsterdam, 1658.

[3] C. Barleum. Res Brasiliæ, imperante Illustrismo. D. I. Mauritio Nassoviæ, etc., Principe. Accedit G. Pisonis tractatus de Aere, Aquis et Locis. (This work is commonly known as "Rerum per Octennium in Brasilia.") Editio secunda, Clivis, 1668. (First ed. Amsterdam, 1647.)

[4] Pierre Moreav. Histoire des derniers trovbles dv Brésil entre les Hollandois et les Portvgais, p. i, Paris, 1651.

If any one acquainted with the reefs should say that they were entirely covered at high tide, there would be some one else equally well acquainted with them to contend and to prove that they were never entirely covered.

But as long as the unbroken reef rocks do not rise beyond the reach of the highest storm tides we are not justified in assuming that they have been elevated.

There has been a certain *apparent* recession of the sea, due, however, not to the elevation of the land, but to the silting up of the marshes, estuaries, lakes, and mangrove swamps behind the reefs.

In 1881 MM. Victor Fournié, sometime city engineer of Pernambuco, and Émile Beringer, his assistant, published a "mémoire sur le port du Recife"[1] accompanied by a carefully made (in 1876) map of Pernambuco and its environs. On this same map is an overprint of the best map it was possible to compile from those made by the Dutch, of the same region, during the first half of the seventeenth century. This map is the most important document we have of the kind bearing upon coast changes within historic times. It shows that since these early maps were made, channels then open have filled up, others have been much narrowed, and large areas, then either swamps or quite under water, have become dry lands and have been built up with houses. M. Beringer remarks (p. 20), "The São José quarter was a great marsh covered at high tide," while the width of the channel at the Recife bridge was nearly half as great again as it was in 1876.

Conclusions. — The statements here cited and the facts given, some of them dating back to the first half of the sixteenth century, — more than three hundred years ago, — suggest, if they do not show conclusively, that there has been no striking, or even, to the ordinary intelligent observer, perceptible change in the reefs from that time to this, while the channels then open behind them have been gradually filled up. If, then, there has been an elevation or depression of this coast within the historic period it has been very slight indeed. The recession of the sea at the rate of "ten fathoms in thirty years" as given by Capanema is quite out of the question.

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[1] Bijbladen van het Tijdschrift van het Aardrijkskundig Genootschap. Amsterdam, 1881.

CHANGES WITHIN RECENT GEOLOGIC PERIODS.

Views of former writers. — It is somewhat remarkable that all those who have seen this coast and expressed views about its history have thought it to have been elevated within recent geologic times. These writers are, Barão de Capanema,[1] Liais,[2] Hartt,[3] and J. Clarke Hawkshaw.[4]

Thomaz Pompeo de Souza Brasil, in his valuable Ensaio Estatistico da provincia do Ceará (p. 49), says that at the Barra do Pacotí in Ceará, "as in Bahia and Rio de Janeiro, proofs are seen of the elevation of the coast," but he does not say what these proofs are.

It is but fair to these writers that their views and their reasons for holding them should be given. On the other hand, it is but just to recall the fact that a theory becomes really important only when it is supported by adequate evidence.

I shall therefore give very briefly what the authors cited regard as evidence of the geologically recent elevation of the coast, and at the same time my own reasons for looking upon the bulk of this evidence as unsatisfactory.

Hartt presents tangible evidence of elevation along the coast about Rio de Janeiro, and for some distance north of there. This evidence consists of sea-urchin holes, and old water-lines above tide-level on the island of Maricas, near Rio, on the great conical hill at Victoria, and on the island of Sant' Anna.

In the article cited Hawkshaw speaks of conclusive signs that the coast has recently risen" and of "unmistakable signs . . . of a recent elevation of the coast," but he does not say what these signs are.

The following are adduced by Liais as facts in support of the elevation theory: —

1. The schistose structure of the reef rocks.

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[1] Trabalhos da Commissão Scientifica de Exploração. 1. Introducção, p. cxxi, cxxxvii. Rio de Janeiro, 1865.

[2] E. Liais. Climats, géologie, etc. du Brésil, p. 256–261. Paris, 1872.

E. Liais. L'Espace Céleste, ed. 2, p. 545–548. Paris (1881?).

Compt. Rend., 1860, L., p. 762–763.

[3] Geology and physical geography of Brazil, p. 35, 36, 42, 71–72, 344.

[4] Quar. Journ. Geol. Soc., 1879, XXXV., p. 241–243.

2. The inclination of the reef beds.

3. The elevation of the stone reefs beyond the reach of the high tides. (Capanema speaks of the recession of the sea in the same sense.)

4. The lakes along the coast. (Capanema refers to lakes shut off by sand-banks.)

5. The fixed dunes of the coast.

To this list may be joined two additional points held by Capanema; namely: —

6. Islands joined to the mainland.

7. The conversion of a deeply indented coast-line into a weakly indented one.[1]

It may be said at the outset that whether there has or has not been an elevation of the coast in question, in my opinion the facts to which appeal is made in these cases are either not facts at all, or else they do not admit of the interpretations given them.

These points will be briefly considered in their order.

1. *The schistose structure of the reef rocks.* — It is presumed that the idea here is that schistosity would have been produced by orographic movements. However that may be, in the many kilometres of stone reef examined by the present writer, what is commonly regarded as schistose structure has not once been observed in the reef rocks. In places the rocks sometimes contain mica, and are therefore somewhat foliated, and it seems probable that this foliation may have been regarded by Liais as schistosity. The mica that causes the foliation was deposited with the sand.

2. *The dip of the reef rocks.* — Liais considers the angle of slope of the beds (*op. cit.*, p. 545) as having been produced by orographic disturbance, the inference being that the strata were originally horizontal. It is true that the beds of the rock reefs do have a dip varying between two and twenty degrees, and in a few cases running a little higher. But the dip is usually low and uniform and invariably toward the sea; it is simply the bedding of the beach sands of which the reefs are made. Such dips may be seen in the wet sands of the present beaches.[2] I have lately made notes upon the angles of the wet sand uncovered at low tide along the coast of Pernambuco and Alagôas. These angles run as high as twenty-four degrees in false beds. A newly formed delta in the Una

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[1] Mittheilungen von Dr. Petermann, 1874, p. 230.

[2] A. de Lapparent. On this subject see Traité de géologie, p. 173, 175. Paris, 1885.

L. Élie de Beaumont. Leçons de géologie pratique, Vol. I., p. 226–227. Paris, 1845.

had a false dip on the steep front varying from 34° to 37°. An unusually steep beach up and down which waves were running at the mouth of Rio Sapucahý had a slope of 11°.

Liais states, however, that these reef beds are sometimes vertical. This is true, but in no case has the writer seen a reef rock *in place* in a vertical position. The hard reef rocks rest upon soft sands; it frequently happens that the reef is undermined by currents, and huge blocks of stone falling in the soft sands are left tipped about in various positions and even standing on end.

3. *Reef rocks above high tide.* — Whether rock above high tide can be accepted as evidence of elevation depends on how the rock was formed. M. Liais speaks of the reef rock as having been formed beneath the sea.[1] If that were the case, the reasoning might pass, but it is doubtful, to say the least. The toppling over of a large mass in the manner just referred to sometimes lifts one end out of the water and beyond the reach of high tide. Besides such cases there are instances of the hardening of beach sands beyond the reach of the tides. This hardening may be caused either by spray being blown by the wind several metres higher than the tides rise, or it may be produced by rain water dissolving the lime from the upper layers of sand and depositing it again lower down. There are many excellent illustrations of this hardening of sands far above tide on the island of Fernando de Noronha[2] and at other places in the world, though the writer does not remember to have seen any on the Brazilian mainland.

The case of the recession of the sea cited by Capanema occurs in the State of Ceará. He says of it: "In Ceará the elevation has been considerable near Aquiraz in a place where the sea has receded *ten fathoms in thirty years*, and to this the inhabitants cannot apply their favorite explanation — the accumulation of sand — for the poles have not been covered."[3] The italics are mine. He does not state whether or not the land uncovered is hard rock or soft sands and clays, and in order to judge of the meaning of such phenomena it would be necessary to know this, and also to know the angle of the newly exposed surface. It is certainly not to be supposed that a vertical recession of ten fathoms, or anything approaching it, has taken place in thirty years.

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[1] L'Espace Céleste, p. 545, 548.

[2] J. C. Branner. Geology of Fernando de Noronha. Amer. Journ. Sci., 1889, XXXVI., p. 160–161.

J. C. Branner. The æolian sandstones of Fernando de Noronha. Amer. Journ. Sci., 1890, XXXIX., p. 247–257.

H. B. Woodward. The Geology of England and Wales, ed. 2, 1887, p. 546–7, 550–1.

T. McK. Hughes. Ancient beach and boulders near Braunton and Croyde, Quar. Journ. Geol. Soc., 1887, XLIII., p. 657–670.

[3] *Op. cit.*, p. cxxxvii.

4. *Lakes near the coast.* — Liais's idea seems to be that the lakes near the coast are produced by elevation and that their basins are the lower portions of the former sea bottom, while Capanema speaks of the shutting off of lakes by sand banks — apparently understood to be banks of submarine origin.

There can be no doubt that lakes might be formed in this way; there may be a question as to whether the lakes of the Brazilian coast have been so formed. This question will be considered later.

5. *The fixed dunes of the coast.* — Liais assumes that an elevation of a coast on which sand dunes had been forming would put a stop to the beach supply of sand, and that the dunes would for this reason cease to move.

Where it is a question of small vertical elevation, such a result is not to be expected from such a cause. When dunes are once set going over large areas no new supply of sand is necessary to keep them in motion. This is too well known to require discussion. In northern Nebraska, a thousand miles from the sea-coast, are extensive areas covered by shifting sand dunes. Many of the great deserts of the world, such as the Colorado desert, the Sahara desert, the Mojave desert, and the deserts of the lofty arid regions of South America, bear witness to this fact.

If it be assumed that the case is different on the coast-line where the dunes occupy a narrow belt, then it comes to be a question as to whether the dunes along the Brazilian coast are or are not now in motion. As a matter of fact the dunes of this coast, with certain exceptions, are not stationary, as the writer knows both from personal observation and from the statements of other trustworthy writers. The dunes are moving along the coasts of Bahia, Sergipe,[1] Alagôas, Rio Grande do Norte, Ceará, and Maranhão. In these states the writer has seen many miles of dunes, and they are known to every one who has travelled much along the coast. Hartt mentions them in Bahia,[2] Sergipe, Rio Grande do Norte, and Ceará. Koster also mentions those of Rio Grande do Norte.[3] In the last-named state the dunes stretch for miles along the coast both north and south of Natal, and at this last place efforts have been made by the government for years to prevent the dunes from filling up and destroying the harbor.

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[1] J. C. Branner. The Cretaceous and Tertiary geology of Brazil. Trans. Amer. Phil. Soc., XVI., p. 375. Philadelphia, 1889.

[2] Geology and physical geography of Brazil, p. 345–346; 355; 383; 394; 455; 458.

[3] Henry Koster. Travels in Brazil, 2d ed., Vol. I., p. 102. London. 1817.

North of the village of Bahia Formosa moving sand dunes form the coast as far as the mouth of Rio Cunhahú. Some of these dunes rise to a height of sixty metres and are now blowing inland. Ordinarily they are about twenty metres high, and the sand is blown inland over a caatinga forest.

A score or more of instances might be given of the movement of the dunes of the coast of Rio Grande do Norte. These, however, must serve, especially as the validity of the argument based upon their being fixed is not recognized.

Pompeo de Souza Brasil observes that the dunes of Ceará are always in motion, "so that the coast is ever changing its aspect." In some places he says the dunes extend for leagues into the interior and even close the mouths of streams and turn them into lakes.[1]

Capanema says the Ceará dunes are sometimes three hundred palms high[2] and Hawkshaw[3] notes that they "stretch for miles on each side of the city of Ceará," while at Maranhão, Ponta d'Areia, "the soldiers of the fort have much difficulty in keeping themselves from being engulfed" in sand.

"A curious circumstance of this part of the coast (northeast Brazil) is that all the western sides of the river mouths are covered with vegetation and mangrove swamps, while the eastern sides are barren sand wastes. This is caused by the constant action of the east wind on the dunes; the sand is driven toward the west until it comes to a river and there it falls."[4]

6. *Islands joined to the mainland* (Capanema). — A study on the ground of the physical geography of the Brazilian coast makes it plain that former islands have, within geologically recent times, been joined to the mainland. But such joining cannot alone be accepted as evidence of an elevation; the question is, how was this joining brought about?

If we imagine the Pernambuco coast elevated an amount equal to or

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[1] Pompeo de Souza Brasil. Ensaio estatistico da provincia do Ceará. I., p. 10-11. J. E. Wappæus. A geographia physica do Brasil, p. 15. Rio, 1884.

[2] Trabalhos da Commissão scientifica de Exploração. I. Introducção, 1862, p. cxxxvi–vii.

[3] Melhoramento dos portos do Brazil, Relatorio de Sir John Hawkshaw, p. 80–81, 91. Rio de Janeiro, 1875.

[4] J. E. Wappæus. A geographia physica do Brazil refundida, p. 15. Rio de Janeiro, 1884.

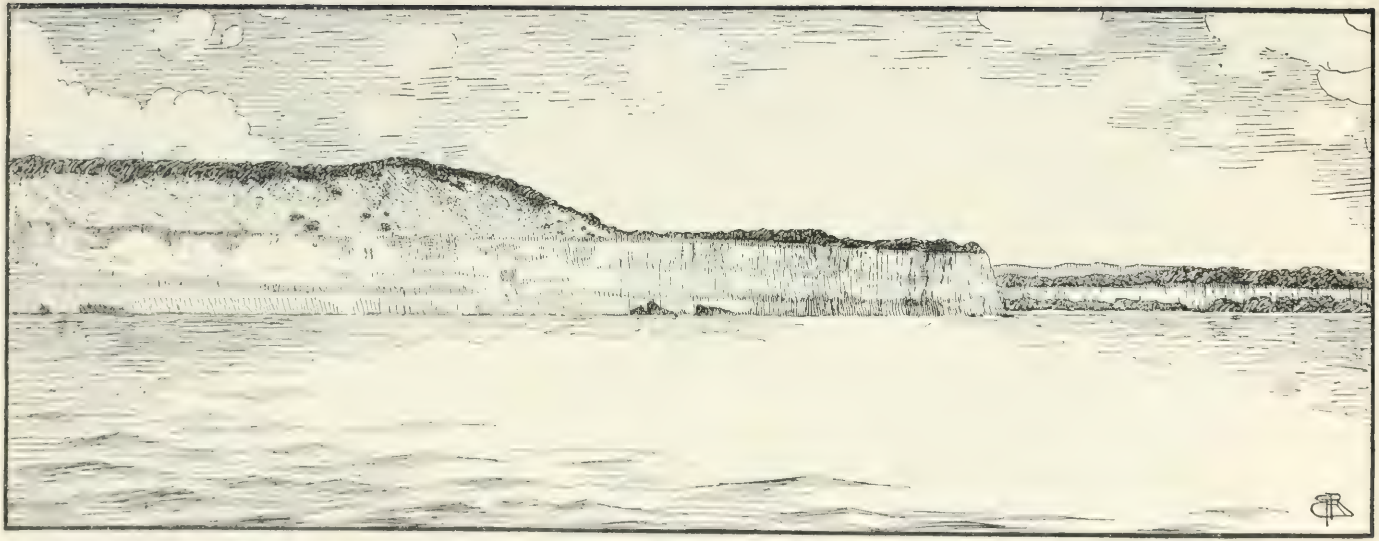

Fig. 66. Bluffs at Pipa capped by ancient sand dunes. From photographs taken from the anchorage.

somewhat greater than the depth of the water between the mainland and the island of Santo Aleixo, that island would of course be joined to the land by this process of elevation.

But islands are not joined to the mainland solely by this process of elevation; they may be united by a process of silting up, by the building out of spits or accumulations over an intervening shallow bottom. A convenient illustration of what I mean is furnished by the Pão d'Assucar at Rio de Janeiro. The Pão d'Assucar was not long ago an island having a shallow water passage between it and the *Morro de Babylonia* just where the *Escola Militar* now stands. The waves, however, have thrown the coast sands back into this passage until it has been completely filled up and the Pão d'Assucar has thus been joined to the mainland.

It will be shown later that there has been a depression of the northeast coast of Brazil. Before that depression took place there was a valley southwest of Cabo Santo Agostinho opening broadly toward the sea. In this valley were a few isolated hills left by the erosion of the Tertiary highlands. When the depression occurred, the bottom of this valley went beneath the water, and these isolated hills were left as islands in the big bay. In the course of time this entire bay has been filled with sands and silts and turned into dry land, and in the process these former islands have been united to the mainland.

At Ilheos, State of Bahia, a rocky hill at the mouth of the harbor, known as Morro de Pernambuco, is joined to the mainland by a sandy neck that has the appearance of being a spit lately built in. It is evident therefore that while islands have been joined to the land, this joining cannot alone be accepted as evidence of an elevation of the coast, but may indeed come from a movement in quite the opposite direction.

The chief objection to the statement by Capanema as it stands, however, lies in the absence of specified cases.

7. *The straightening of the coast-line* (Capanema). — The line of reasoning in the case of the straightening of the coast-line is not indicated by Barão de Capanema, but it is probably meant that on account of the sea bottom being less rugged and less scored than the land surface, an elevation would at once yield a comparatively even beach-line, while a depression, owing to the unevenness of the land, would give a very crooked one. But a coast-line may be straightened by quite another process; namely, the process of destructive attack by the sea. The facts presented hereafter appear to warrant the belief that the

ancient indentations of this coast have been obliterated by time and the sea.

Comparative effects of elevation and depression. — The relations of the reefs to the shores and to the coast topography makes it necessary to deal with the topographic forms of the reefs and to understand by what processes and in what order they originated.

The general effects of elevation on any coast will be considered first, and afterwards the effects of depression, and then by comparing the littoral forms thus produced with those of the Brazilian coast the writer will try to determine by which of these movements its present features have been produced.

Effects of elevation. — If any coast were considerably and abruptly elevated the old beach-line would form a terrace, the old undercut shores would be marked by an incised line produced by the former work of the waves, the coral reefs of the region would be exposed, the polyps killed, and the remains of marine animals, especially the Mollusca, would be left strewn across the newly raised land. The streams would have their currents increased about their former mouths and would immediately begin to cut into their rock bottoms and to make deep, steep-sided channels. If there were partly enclosed bays or lakes along the former shores, their outlets would cut deep channels back into the lakes and they would be drained at once. Inasmuch as the irregularities of the land, on account of subaerial erosion, are more marked than those of the sea-bottom, a depression would, as a rule, yield a more indented coast-line, while an elevation would yield a coast with but few harbors.

An elevation of three or four metres on this Brazilian coast would produce a peculiar effect upon the stone reefs; the waves would undermine the reefs, for as has elsewhere been shown, they are hardened only to this depth, and they would break into angular blocks and strew the newly made beach with their remains.

Effects of depression. — If a considerable depression took place on a sea coast, the valleys near the coast would be flooded and would become bays, narrow estuaries, or fjords, according to the shapes of the valleys. In general, the coast-line would have the dentritic form suggested by the coast of Maine more or less marked, according to the relief of the region before the depression took place.

This is so universally true that Dr. James Geikie in his recent work upon "Earth Sculpture" states (p. 328) that, "All highly indented coast lines are evidence that the land is sinking or has recently sunk." Lord Avebury, in his "Scenery of England," observes (p. 125) that, "When the land is sinking . . . the drowned river valleys make the coast irregular and complicated."

Another characteristic of recently sunk coasts is that fringing islands usually abound along them. Immediately following a depression sediments brought down by the streams and washed by the waves from the promontories and fringing islands silt up the bays and lower stream channels, and only such channels are left as the tides are able by their scouring action to keep open. At first the tide flows further inland and there are many harbors on the new coast, but in the course of time the silting up of the estuaries crowds the tide back to the open coast-line. If the depression goes on more rapidly than silting, the tides extend further and further inland; but if silting and the constructive work of the sea are more rapid the tides are kept back. Depression brings within the reach of the waves a new surface and adds greatly to their cutting power, and consequently large quantities of silts are produced. If the prevailing winds blow on shore, as they do on the Brazilian coast all the year round, the heavier silts cut from the headlands are thrown back into the bays rapidly, the beaches of sand extend seawards, the closing of the mouths of streams and estuaries are hastened, and there is a general tendency to form a straight shore.[1]

The marshes built out in the depressions are soon covered with mangroves, and the streams in some cases wander behind the beaches for some distance before breaking through them to enter the sea. We thus eventually have the coast marked by a succession of tide marshes and lakes, with long straight beaches in front of them, and with here and there a headland coming down to the sea.

If, however, the silts cut from the shore-line are swept away by the currents, either along the shores or seawards, the coast soon exhibits a continuous bluff and the sea encroaches upon the land until an equilibrium is reached between the resistance of the shores and the sea bottom on the one hand and the waves and currents on the other.

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[1] The question might be raised as to whether the materials cut from a continental shoulder would be thrown on shore or carried seaward by the undertow. I do not think a fixed rule for this can be given. In some cases one thing happens, and in others the other. In some localities the fine black silts containing marine organisms are constantly thrown back into the estuaries, in other cases the coast is kept clear of fine silts by the undertow.

(The estuaries of the Severn, etc. By W. J. Sollas. Quar. Journ. Geol. Soc., 1883, XXXIX., p. 619; discussion by Mr. Whitaker, p. 625–626.)

Postscriptum.— In a late article Mr. Fenneman points out that waves of translation tend to carry the materials on the shores upon which the waves break, while waves of oscillation move materials in the direction opposite to that in which the waves move. (Journ. Geol., Jan.–Feb., 1902, X., p. 13–14.)

If evidence can be adduced from other coasts concerning whose history we have more information, the case of the Atlantic coast of the United States from New York to Florida may be cited. This coast is sinking[1] and is characterized throughout a good part of its length by long straight barrier beaches, sandspit harbors, and the silting up of the shallow waters between the shore and the land barriers.

Forms on a stationary coast. — If a coast is at a standstill (not completely stable, for that is probably not true of any coast), the headlands are attacked by waves, streams bring down silts from the land areas, and these materials are thrown back upon the shores at favorable places, forming spits, bars, and barrier beaches, while estuaries and embayments are silted up and turned into dry land.

The forms produced upon an old or stationary coast are therefore different from those produced upon a sinking one in that there are liable to be fewer harbors or other indentations on the older or stationary coast, and that islands generally common on a depressed coast are liable to have been washed away. Or as Dr. James Geikie puts it, "A gently sinuous or profusely curved outline indicates old coasts."[2] Gilbert says that "simple contours and a cordon of sand, interspersed with high cliff, make the mature coast."[3]

Application to Brazil.

Evidences of depression. — As a rule, evidences of depression are less satisfactory, or rather they are less impressive, than those of elevation, because the parts principally affected are carried down out of sight beneath the water.

To any one acquainted with the physiographic features of the northeast coast of Brazil, however, it is evident that those features agree in the main with those of a stationary coast or with those produced by depression and age rather than with those produced by a recent elevation. There are very few islands, if we omit the coral reefs; the coastline is low as a whole; here and there headlands come down to the water's edge, and between these the flat-floored valleys are covered with mangrove swamps or tide marshes. To be specific, however, we shall mention what are regarded as more or less satisfactory evidences of this depression.

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[1] N. S. Shaler, Thirteenth Ann. Rept. U. S. Geol. Surv. for 1891–1892, Plate II., p. 127. Washington, 1893.

[2] Earth Sculpture, p. 317.

[3] G. K. Gilbert. Lake Bonneville. Monograph I. U. S. Geol. Surv., p. 64. Washington, 1890.

Open bays. — In all probability those geographers who have expressed the opinion that the Brazilian coast is one of recent depression have based their opinions upon the peculiar forms of the bays of Rio de Janeiro and Bahia. These bays not only have many of the peculiarities of harbors formed by depressions, but may even be accepted as the very types of such harbors.

Before the depression took place Bahia was a hilly, almost a mountainous region. Its streams were rapid, its valleys steep-sided and v-shaped; its hills were on the whole even-topped, but erosion had worked down among them until many of these were left as isolated peaks above the lowering valleys about them. Most of the streams flowed approximately where they now flow, but those now entering the bay united in the bottom of a broad valley and flowed out through what is now the mouth of the bay into the sea. All that is now known of the date of this erosion is that it was post-Eocene.

When the great depression came, the Bahia valley sank and the waters of the ocean backed up into it and made the bay of Bahia very much as we now see it. The scour of the tides has kept the entrance to the bay open, but the upper ends or indentations of the bay have been silted up with the aid of the encroaching mangroves. The tops of some of the hills were left sticking above the surface as islands. Some of these hills were cut off by the waves, and others were left as islands, and are now known as Mare, Ilha dos Frades, Madre Deus, Ilha das Fontes, etc. Itaparíca and Ilha Santo Amaro became islands at the same time.

The Bay of Rio de Janeiro has had a similar history. Its basin was carved out by subaerial erosion when the land stood at a higher elevation. It sank and water flowed over and filled the valley leaving it a broad but not very deep bay. Some of the original islands of the bay had only shallow waters between them and the mainland, and these shallows were eventually built up by the shore waste thrown upon them until the islands were joined to the land. The Pão d'Assucar case cited on page 124 is an illustration of this process.

The Bay of Santos, about 36.5 kilometres along the coast southwest of Rio de Janeiro, is an excellent illustration of an open island-filled bay smaller than that of Rio de Janeiro formed by a depression of the land. This bay is now almost entirely choked up by the silts washed into it from the surrounding mountains and thrown back into it from the coast.

The accompanying plate (5), made from the beautiful topographic sheet just issued by the Commissão Geographica e Geologica de São Paulo under Prof. O. A. Derby, shows the general features of that interesting region.

The Serra do Mar, from an elevation of over one thousand metres, here slopes abruptly beneath the flat mangrove swamps that lie along its base in the neighborhood of Santos. These swamps, cut here and there by winding tide streams, extend up and down the coast, but are interrupted now and then by headlands — like that at Guárujá — that are really mountain spurs extending down to the sea.

The hills over the plains about Santos are mostly mountain-tops protruding from the mud and sands that have accumulated in the original bay since the depression took place. Morro do Taipú, Ponta de Itaipú, Morro do Xixova, and Morro Itararé were all originally the crest of a ridge that continued past Barnabé Island in the direction of Pico Jacoareguáva, while Ponta Mandúba was the crest of another ridge passing Guárujá in the same direction. The hills south of the Praia de Pernambuco were the crest of another of these parallel ridges.

A striking thing about the ports of Brazil is that the small ones have all been choked up by coast débris, and only the two big ones, Bahia and Rio de Janeiro, have been able, on account of the depths of their mouths and the consequent scour of the tides, to keep their basins open. But even these large ones are filling in from their upper ends, a process greatly hastened on the coast of Brazil by the growth and encroachment of mangrove plants.

Coast lakes. — Lakes may be formed along a coast by an elevation bringing up closed basins — accidental forms of the sea floor,[1] or they may be caused by a depression of troughs, valleys, or shallow-mouthed estuaries whose ends become closed in time by shore accretions, however made, but generally the result of the destructive and constructive work of the sea. The strong winds and currents that set against the Brazilian coast the whole year round make the contest between land forces and sea forces an unequal one; the sea is aggressive and always gaining. The headlands are cut away and their remains thrown into every indentation of the coast, damming in rivers and obliging them sometimes to wander for kilometres behind huge spits before they can escape to the sea.

If, with these two methods of lake-forming in mind, we attempt to get at the history of the Brazilian coast lakes, we find that information regarding their surroundings is too meagre in most cases to enable us to reach firmly established conclusions. In certain cases, however, the topography is so constant in its general features that we feel warranted in drawing conclusions. Certain of the lakes of the State of Alagôas, for example, afford good examples of lakes produced by coast depression.

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[1] Such as are apparently meant by Capanema. Petermann's *Mittheilungen*, 1874, p. 230.

The northernmost of these lakes, the Lagôa do Norte, is surrounded on three sides by rather steep-faced Tertiary hills of soft sedimentary rocks. The slopes of these hills are of forty-five degrees and in places even more.

I learned from Mr. H. Haynes, Superintendent of the Alagôas Railway, that a well was driven at the railway shops near the foot of this bluff in the city of Maceio to a depth of two hundred metres, — all the way in loose materials. The inference is that the steep slope of the Tertiary hills continues beneath the surface and that the filled-in sediments are more than two hundred metres in thickness.

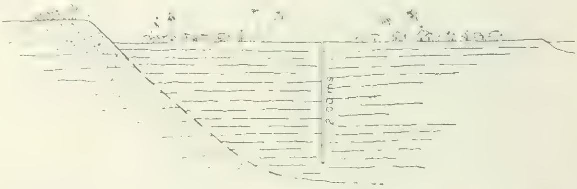

FIG. 67. The deep well section at Maceio and its relation to the rocks of the hills above the city.

Where the Alagôas railway runs along the lake shore in some places there is barely room for the road-bed between the lake and the hills, while at other places broad meadow-like plains or mangrove swamps lie between the lake and the hills. At still others the line of the road crosses flat-bottomed valleys in passing from one spur of the hills to another. These hills — here steeper and there of gentler slope — extend more than three fourths of the way round the lake from Maceio at its northeast corner to the east of Coco Seco on the southwest — leaving only the ancient mouth of the bay with a flat low border of sand between it and the sea.

The lake is now very shallow, so much so that it is navigable even for *barcaças* (small boats drawing a little more than a metre of water) only along one channel on the south side.

Seen from the lighthouse or from the hills that overlook Maceio, the coastal belt inland is mostly one broad flat-topped table-land dropping off abruptly on the coast. This table-land is made of sedimentary rocks that lie in nearly horizontal beds, laid down during Tertiary times.

We can perhaps best appreciate the process by which these lakes are made by returning in our minds to the conditions that must have prevailed about the end of the period during which these sediments were deposited. The beds were then at or below sea-level; subsequently they were lifted vertically from beneath the water and stream erosion began to cut valleys in them, while the waves of the sea attacked their margins. In the course of time broad valleys were eroded out where we now have Lagôa do Norte, Lagôa Manguaba, Jiquiá, etc. After the cutting of these valleys there came a downward movement which carried the bottoms of all of them below the level of the sea, and made bays of them. But inasmuch as land erosion continued over the part still out of water the streams carried their sediments into these bays and began to silt them up. The sea also, cutting sands from the headlands, threw them

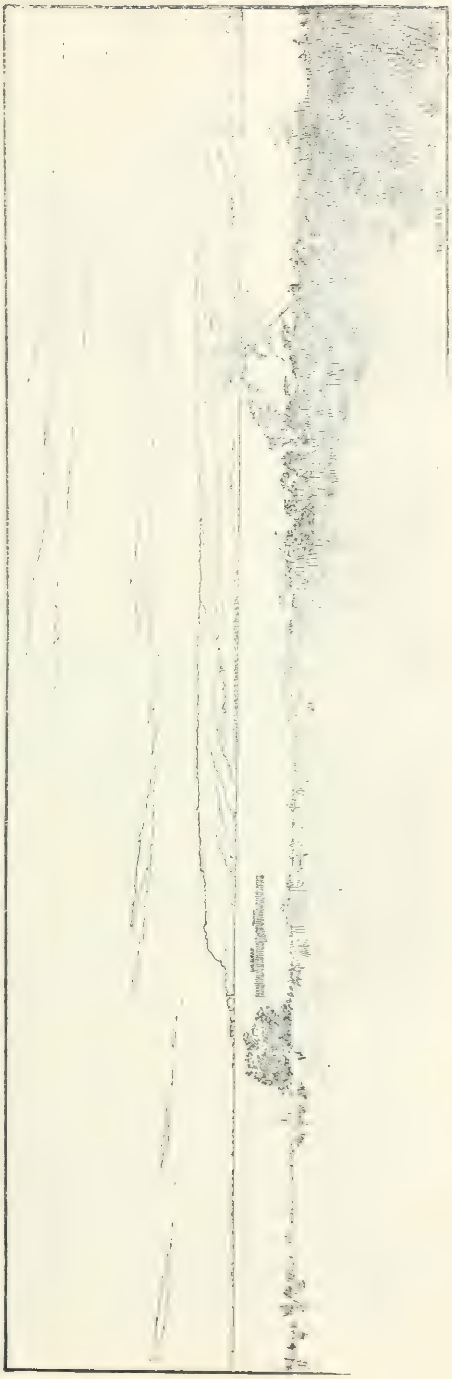

Fig. 68. Lagôa do Norte near Maceio. From a photograph taken from Fernão Velho.

back into the estuaries and gradually formed bars across their mouths, choking up their outlets, and thus turned them into brackish water bodies. Their end it is easy to foretell: they will gradually become smaller and shallower, and at no distant day will be great marshes, each with a sluggish stream winding through it, and still later low flat *varzeas*.

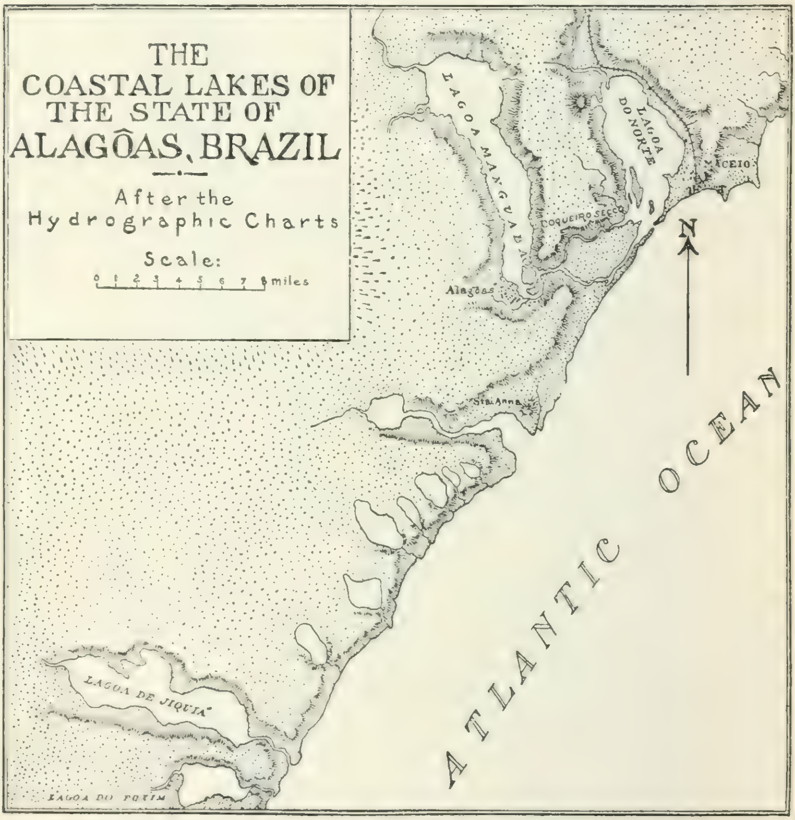
THE COASTAL LAKES OF THE STATE OF ALAGÔAS, BRAZIL
After the Hydrographic Charts
Scale:
0 1 2 3 4 5 6 7 8 miles
LAGOA MANGUABA
LAGOA DO NORTE
MACEIO
COQUEIRO SECCO
Alagôas
N
Sta Anna
ATLANTIC OCEAN
LAGOA DE JIQUIA
LAGOA DO POXIM

Fig. 69.

On the coast between Rio de Janeiro and Cape Frio are several lakes shut in by the coast sands that have been thrown across the mouths of valleys opening toward the sea. The country immediately north of these lakes is a mountainous one, the land rising to elevations of from one thousand to fifteen hundred metres in a distance of thirty or forty kilometres. Between some of the lakes low headlands come down to the beach. Lagôa Maricá, for example, has such headlands at both its eastern and western ends; so has Lagôa Gururupira; Lagôa de Araruáma has the peaks of Cabo Frio at one end and the hills of Ponta de Saguaréma at the other. These lakes thus stand on the sites of sunken coastal valleys whose mouths have been closed by the shore waste, and whose upper ends have been silted up by materials brought down by streams.

Sand banks or bars are liable to be built across any sharp curve in a coast-line; behind these bars lakes and pools are formed, and later these silt up, forming marshes and eventually land. On the Brazilian coast some of the lakes are fresh and some of them are brackish according as the influx of fresh water is large or small.

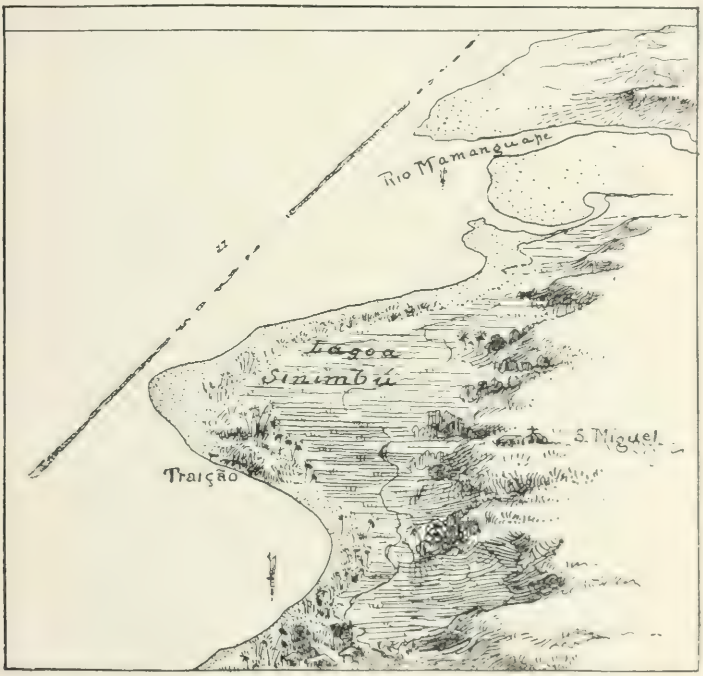

Fig. 70. Bird's-eye view of the region about Traição and the mouth of Rio Mamanguape, showing the relation of the stone reefs to the shores.

At Traição, State of Parahyba do Norte, the Lagôa de Sinimbú, a fresh-water lake, is shut in by a narrow neck of sand that compels the drainage to find an outlet to the sea through the Mamanguape River several kilometres away. The entire seaward rim of this lake is made of recent sands. South of Traição this barrier is about two hundred metres wide, and is piled with dunes, some of them as much as ten metres high, but at and north of the village the rim is only about forty metres wide and two or three metres high. The land side of the lake is of Tertiary (?) sediments rising in a plateau from twenty to thirty metres high. A section from São Miguel church on these hills across the lake is given herewith.

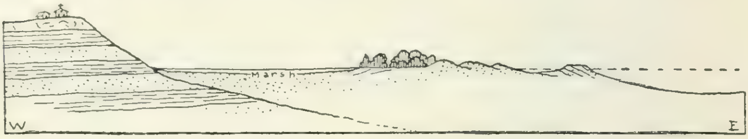

Fig. 71. Section from the hills at S. Miguel church across Lagôa Sinimbú.

The history of the place appears to be as follows: when the Tertiary sediments that form the coast plain rose from beneath the sea, they reached an elevation considerably higher than that at which they now stand. Erosion followed, cutting narrow valleys in these beds; then came a depression that carried beneath the sea the lowlands near the coast and the lower ends of some of the valleys. Marine erosion on the newly exposed beach-lines tore down the headlands, and the sands were heaped up by the waves as sand-bars which, in time, separated the salt from the fresh water.

The lakes along the coast of Ceará are produced, in my opinion, in one of two ways, either by the throwing up of beaches by wave action like those on the sandy west coast of France,[1] or else by the shifting sands of the dunes damming back or changing the courses of rivers, as is known in Rio Grande do Norte, Ceará, and in Sergipe.[2]

One of the chief reasons for believing that certain lakes have been shut in by the constructive action of the present sea and not simply to have found ready-made basins is that if an opening be made in the rim separating the lake from the sea the breach is immediately closed by the sea. The lower courses of many of the rivers stand in the same relations to the sea as do lakes similarly located, except that the rivers are certainly more capable of keeping their mouths open than are lakes.

Rios tapados. — The city of Recife stands upon a long tongue of land behind and around which flow the Beberibe and Capibaribe rivers. Among the various plans for improving the port of Pernambuco one suggests the cutting of this neck just south of Fort Brum.[1] But this neck has been cut through on more than one occasion, and the breach has been closed by the sea in spite of the fact that the break greatly shortens the course of the Beberibe to the sea.

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[1] André Delabecque. Les Lacs Français, p. 47–49. Paris, 1898.

[2] See J. C. Branner. Cretaceous and Tertiary geology of the Sergipe-Alagôas basin of Brazil. Trans. Amer. Phil. Soc. 1889, XVI., p. 375.

In the Instituto Archeologico e Geographico of Pernambuco is an interesting old water-color of the city said to have been made between 1822 and 1844. This picture shows a break in this peninsula between Fort Brum and Recife. Several persons who have lived for many years at Pernambuco have assured me of such breaks having been made from time to time by the sea and afterwards filled up by the same agency.

On a trip down the coast from Pernambuco to Maceio, made in July, 1899, I observed several instances of sandy necks cut through by the streams behind them and immediately afterwards repaired by the sea.

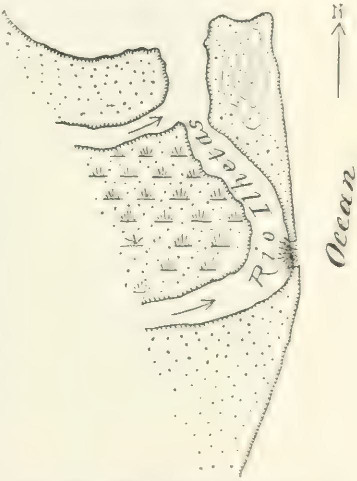

FIG. 72. Breached sand neck, Rio Ilhetas.

At Ilhetas Point (S. lat. 8° 45′ 30″) a small stream, Rio Ilhetas, approaches the coast at right angles, but instead of entering the sea at once it swings northward, unites with another stream, and enters the ocean a kilometre or two away, under the protection of a wide sand-bar. At the time of my visit, near the end of the rainy season, the river at an ebbing tide had broken through the narrow neck of sand that prevented its direct entrance to the sea, and cut a gap as wide as the river and more than two metres deep. But instead of the river being able to keep this new mouth open, the very next incoming tide not only threw the sand back into the opening but piled through on top of it a great cone that the river was now compelled to cut out of its original channel. On the whole, there was a decided loss for the stream.

Again, where Rio Una approaches the sea near Varzea (S. lat. 8° 49′), a similar break was made by a larger stream. The opening was about two kilometres north of the mouth of the river, was 2.3 metres deep, and forty metres wide. The stream opposite the opening is one hundred metres wide and has a strong current. With an outgoing tide during the rainy season the river had sapped the sand-bank that separated it from the sea, but the next incoming tide had thrown the sand back into the opening, and had heaped into it and into the river's channel an enormous delta of new material that considerably narrowed the channel and that the river must now remove. At the next high tide the sea would be able to more than complete the repairs of the breach.

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[1] M. de Barros Barreto. Projecto de doca no porto de Pernambuco. 1865.

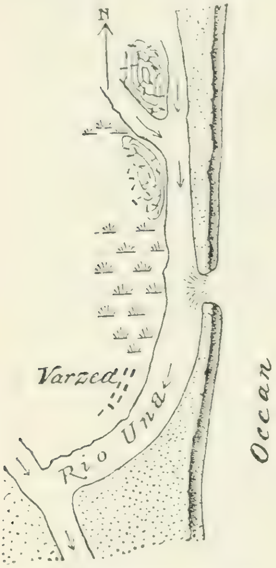

Fig. 73. Breached sand neck, Rio Una.

The same phenomena were observed five hundred metres above the mouth of Rio da Cruz, the small stream next south of Abreu de Una. The breach on the Rio da Cruz was only about sixty metres wide.

With these illustrations in mind let us turn to the case of Lagôa de Sinimbú in the State of Parahyba do Norte. Suppose a flood or any agency whatever should cause the waters from Lagôa Sinimbú to cut through the narrow sandy neck north of the village of Traição. It is evident that the waves would immediately, or as soon as this extraordinary agency ceased to be active, throw the beach sands into the breach and turn the drainage away to the south where it can join its forces to those of the Mamanguape River and get into the sea under the cover of the mangrove swamps, sand-bars, and stone reefs that there protect it from the ocean.

One of the most impressive examples of the damming in of the coast lakes by the sea is that of the Rio Jacaresíca a few kilometres north of the city of Maceio, State of Alagôas.

That stream is shown upon the hydrographic chart as flowing into the sea, and doubtless at one time it did so, but when I passed along that beach in August, 1899, no such stream was flowing across it, and I was informed by residents that for fifteen or twenty years the Jacaresíca had been a *rio tapado*, or stream with its mouth closed.

In this connection I am reminded that there are several small streams along the Brazilian coast known as *rios tapados*. One of these is only a few kilometres north of Olinda on the Pernambuco coast.

The following sketch was made on the coast between Rio da Cruz and

São José, about S. lat. 8° 52′. Here the sea has encroached upon an old mangrove swamp. The two ends of a former channel have been cut across, but instead of these channel ends being left open they have both been closed by sand thrown into them by the sea, thus enclosing two miniature lakes.

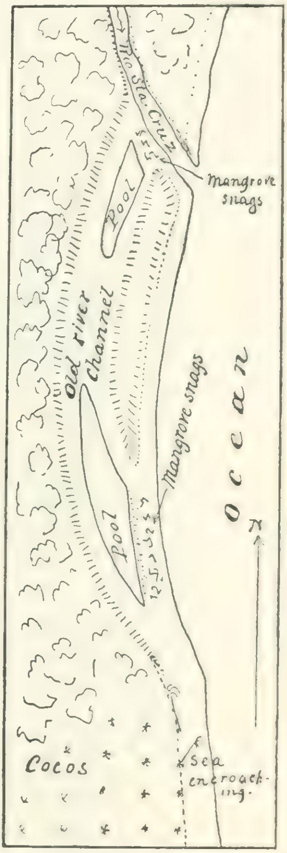

Fig. 74. Sketch-map of the former channel of Rio Santa Cruz.

Hartt mentions such a case on the coast of Espirito Santo: "Just north of the Doce and near the coast is a large lagoon called Monserras. During the dry season this is separated from the sea by the sand-beach, but when the rains come it opens for itself a channel to the sea, which channel remains open until the dry season returns. . . . When I went to the Doce from São Matheos this bar was closed, but on my return, in the latter part of December, it was open and dangerous to cross."[1]

The closing of all these breaches by the sea must be accepted as meaning that the sea along the northeast of Brazil is quite capable of both making and maintaining the embankments that shut the lakes in on the seaward side.

Choked embayments. — A large number of choked up embayments and estuaries along the Brazilian coast might be placed here in evidence. Only a few of them can be mentioned.

The city of Recife itself stands on one of these choked up bays, though rather an open-mouthed one. The hills of Olinda stand at the northern end of the Pernambuco embayment, while its western boundaries are indicated by the line of steep-faced hills that sweep inland past Beberibe, Beberibe de Baixo, Casa Amarella, Monteiro Dois Irmãos, Caxangá, Engenho São João, approaching the São Francisco Railway two kilometres southwest of Bôa Viagem station. From this point the hills swing inland again and only come near the railway at Ilha station, and passing the city of Cabo reach the coast at Pedras Pretas some thirty kilometres south of Olinda.

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[1] Geology and physical geography of Brazil, p. 106.

With the exception of the sandstone reefs there is not a hard rock exposure on this entire beach from Olinda to Pedras Pretas. It is all loose sand heaped by winds and waves a little above high tide-level, and behind the flats of sands near the coast-line are mangrove swamps, old and new, lakes, marshes, *varzeas*, and sluggish streams.

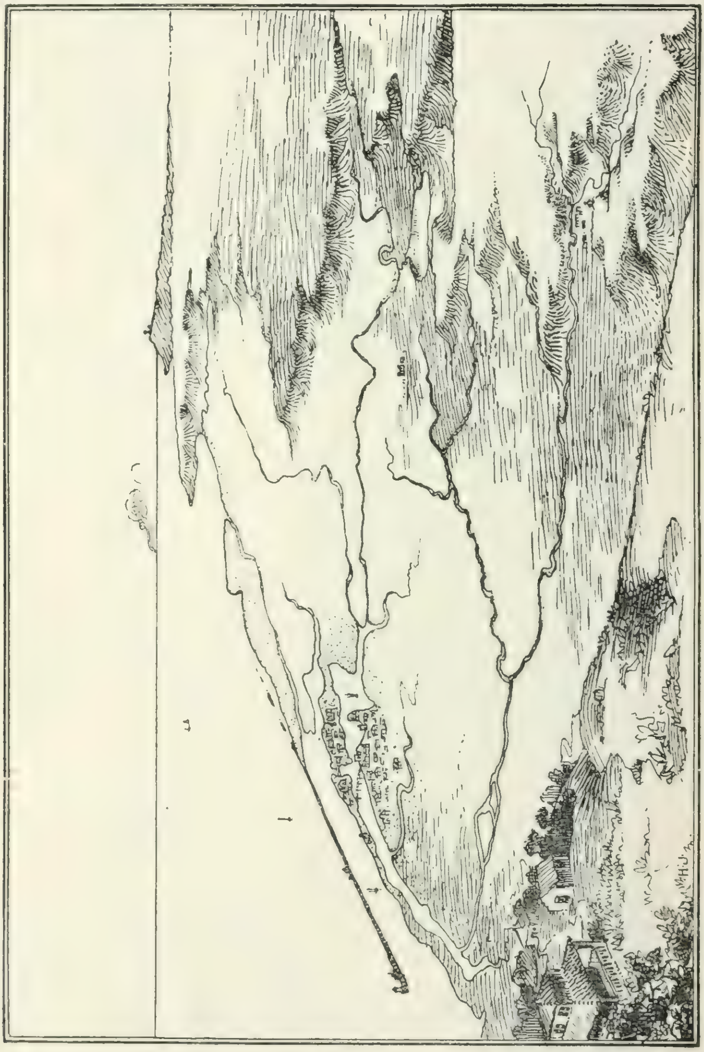


FIG. 75. Bird's-eye view of the Pernambuco embayment.

South of Cabo Santo Agostinho the great sandstone reef stretching from the Barra do Suápe at the old fort on the cape to Cúpe, a distance of twelve kilometres, shuts in another old embayment into which still drain the Suápe, the Tatuóca, the Ipojúca, and the Merepe rivers. The hills that bound this ancient embayment start with the cape, swing inland many miles, and reach the coast again only near Ponta do Serrambý. Within this embayment are a few isolated hills that formerly made islands in the shallow but now silted up bay.

The Rio Parahyba, in its lower course, now flows through a silted up bay that once extended south and west of the city of Parahyba do Norte. Seen from the upper city, this old bay is now represented by the cane-fields, marshes, mangues, and sluggish streams of the Parahyba valley. The filling up has progressed so far that the sands have filled far beyond the old mouth of the bay, and the newly made sand-flats of Cabedello extend to the base of the hills on which Parahyba stands, and almost to Cabo Branco itself.

The Cunhahú River in Rio Grande do Norte is the last remnant of a bay that formerly opened between the hills of Cabo Bacaporý and Bahia Formosa on the south and the hills at the base of which the Cunhahú now enters the sea. This was a long narrow bay that extended many miles inland. Many similar streams along that part of the coast are now characterized by lakes of considerable size in the process of transformation into marshes or dry land.

Depressed valleys. — A characteristic feature of the coast of Brazil from Rio Grande do Norte to Prado, in the southern part of the State of Bahia, is the topography about the streams where they debouch upon the coast. Seen from the ocean, they generally present some such outline as that shown in the accompanying cut.

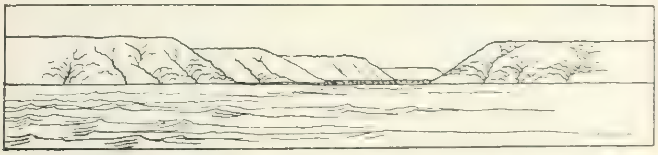


FIG. 76. Type of submerged and silted coast valley.

Such forms are quite in keeping with the theory herein maintained. The present river valleys were cut out when the land stood at a higher level; when the depression took place these valleys were partly submerged, and in the course of time their shallow mouths have been choked with sands thrown up across them by the waves, while their upper portions have been filled up with silts from the land, and with organic matter. There is a large number of small rivers whose lower courses have had this history. Only a few of them need be mentioned.

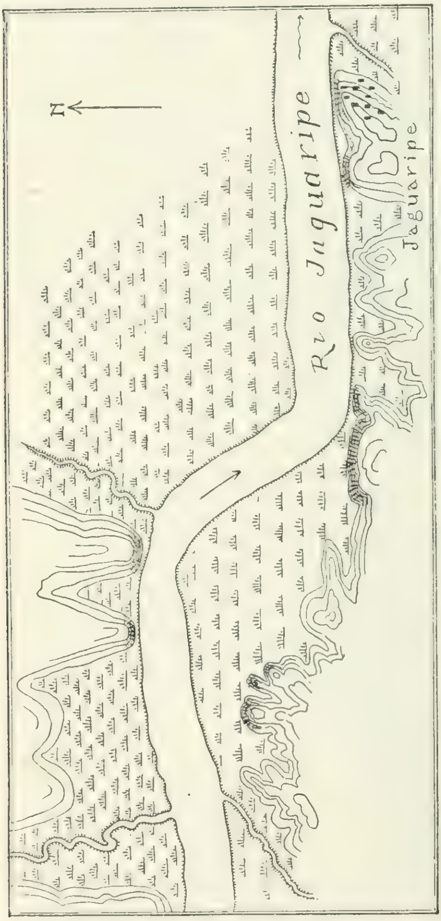


Fig. 77. Sketch of the topography of a part of Rio Jaguaripe, state of Bahia.

Rio Guajú, at the boundary between the State of Parahyba and Rio Grande do Norte, has a broad flat bottom filled with sand, lying between rather steep-faced hills.

Rio Sibaúma, a small stream north of the Cunhahú, has a similar topography about its mouth.

The Pirangý, though almost closed by a high sandbank, has essentially the same general topography.

In the State of Parahyba we have similar forms at the mouth of the Mirirí, north of the capital, and the Grahú, south of the capital, not to mention the larger streams. In the State of Pernambuco similar forms are common, though often modified by having the flat coast sands built out beyond the steeper bluffs, thus merging the flat river valleys into the flat sandy coast plains.

If good maps of them were available, some of the rivers about Bahia, the Jaguaripe, for instance, would illustrate this matter beautifully. The Jaguaripe, however, is very poorly shown upon the hydrographic charts. The sketch-map (Fig. 77), mostly constructed on the spot, will give, not the exact form, but rather an idea of the generalized features of a portion of the region.

The shores along the lower part of the river are all low, and mostly covered with mangrove swamps; the highlands begin at the town of Jaguaripe on the south side; on the north side they begin a couple or three kilometres further upstream. These hills are some thirty-five metres high. They have steep slopes, some of them being nearly perpendicular, that plunge without a break beneath the mangrove flats. When one can get a broad view over these mangrove flats, he sees them ending like a water-line against the foot of the hills. The landward margins of the mangrove swamps now follow for a distance parallel with the stream, and now turn square away from it, run inland for a kilometre or two, and then curve sharply back upon themselves, thus producing a regular dendritic form. In places these swamps are built out in front of hills, in others the river cuts the foot of the hills, and the swamps fill the valleys between them like the membrane between the fingers of the human hand.

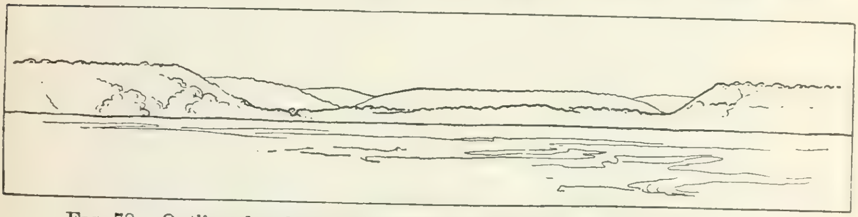


FIG. 78. Outline sketch of the topography at the mouth of Rio Santa Cruz.

The present Jaguaripe river, in any case, is a very crooked one, now washing the rock bases of bluffs, and now winding through the midst of great mangrove swamps.

These are the features of a region having originally a rather sharp drainage and narrow, steep-sided valleys, but now let down until the sea has invaded the lower ends of the valleys, and these valleys are more or less silted up and taken possession of by mangrove swamps.

The mouth of the Santa Cruz river, in the State of Bahia, seen from the north end of the Alagadas reef, has the outlines shown in the accompanying sketch.

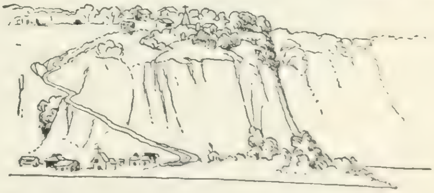


FIG. 79. Sketch of the bluff at Santa Cruz.

The bluffs at the town of Santa Cruz are so steep on the northwest face that they are nearly perpendicular. The sketch below was made from a point further south, and looking due west toward the town.

At Porto Seguro the flat-bottomed nature of the valley is more striking than at Santa Cruz. The hills are the same Tertiary sediments, with valleys cut down in them. At the north edge of the upper city one of these valleys appears not to have been quite deep enough to let the sea into it, but the valley of the Rio Cachoeira being larger, there was here formerly a long narrow estuary that has become silted up and turned into dry land.

The view from the top of the south edge of the plateau near the upper city at Porto Seguro is an impressive one. The slope of the bluffs is close to 45°, the valley is broad, almost perfectly flat, and less than a metre above high tide-level. The sketch on p. 98 will give an idea of the more prominent features of the region.

Some interesting examples are visible on the cliffs exposed north of Prado, State of Bahia. The following sketch shows the *barreiras*, or red clay bluffs, just south of Comoxatiba in the vicinity of the monazite sand deposits.

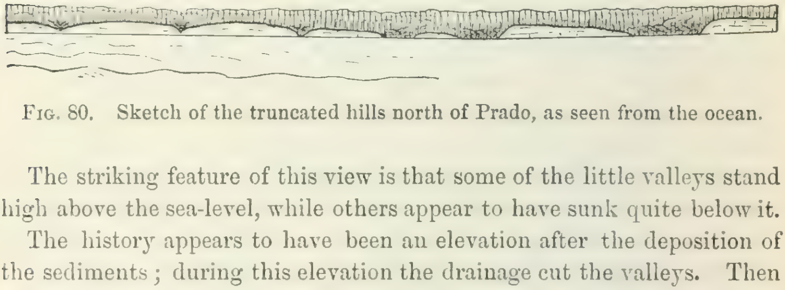


FIG. 80. Sketch of the truncated hills north of Prado, as seen from the ocean.

The striking feature of this view is that some of the little valleys stand high above the sea-level, while others appear to have sunk quite below it.

The history appears to have been an elevation after the deposition of the sediments; during this elevation the drainage cut the valleys. Then followed a depression, and the lower valleys went beneath the sea, while the higher portions were not affected. Marine erosion has truncated and exposed many of these valleys in the bluffs.

That the estuary valleys are sometimes still partly open or not quite filled up is due to the scouring action of the tides. For estuaries with streams entering their upper ends have to discharge at ebb tide more water than they receive during flood tide, hence the outflowing current must be more rapid than the inflowing one. They can only fill up from the upper or landward ends, and by the combined action of mangroves and of silts brought down by the drainage. The seashore silts cannot reach so far up streams.

Should it be suggested that these flat lands might be produced by an elevation of the sea-bottom, I would reply that an elevation of the coast would give the streams greater fall and velocity, and that, instead of silting up as they are now doing, they would at once begin to erode their channels.

The case of Rio São Francisco. — The Rio São Francisco appears to be an exception to the rule that governs the other streams of this part of the coast of Brazil. But the São Francisco is a large stream — the largest one entering the Atlantic between the Amazonas and the Rio de la Plata. It has already been pointed out that there is a never-ending conflict between the land and the sea forces. Along this coast there is a tendency on one hand for the silts to be thrown back into the mouths of the streams, and on the other hand for them to be forced out to sea by the waters of the streams. What the result is depends upon the comparative powers of these two agencies. If the sea is the more powerful agent the mouth of the river is closed and its waters are compelled to dodge behind a reef, island, bar, or bend in the coast-line in order to escape to the sea. Sometimes they must wander for kilometres in search of this protected outlet. Sometimes it happens that the energy of the stream is temporarily increased by floods to such an extent that it is able to break across these wave-constructed barriers and enter the ocean boldly. But when the floods subside the waves resume their control, the new passage is closed, and the stream returns to its former channel.

In the case of the Rio São Francisco the volume of water is at all times so large that it is able to flow squarely into the ocean and to keep its immediate mouth clear by throwing out bars well in front of it.

A slight elevation or depression is not likely to produce changes about the mouth of such a stream as the Rio São Francisco that would be as readily recognized as they would be about a smaller stream. The lower valley has already been silted up far in advance of the highlands, and as one enters the river from the ocean he sees only great stretches of low, flat delta lands about its mouth. The high ground is reached several kilometres upstream — at Villa Nova on the south side, and near Penedo on the north. The valley above these points is broad and flat, but it ends abruptly against the rather steep hills on either side.

I am unable to say whether this topography of the lower river is that of a drowned river valley, or is produced simply by the ordinary floods that annually spread over a large part of it.

Higher up stream — at Piranhas — the river flows over a rock bottom, but this is one hundred and eighty kilometres from the present river mouth.

Downstream the form of the channel is that of a depressed v-shaped valley, and this finally merges into the broad, open, but flat-bottomed valley, with the high banks far apart.

The Amazon is also too powerful a stream to be shut up by its own silts.

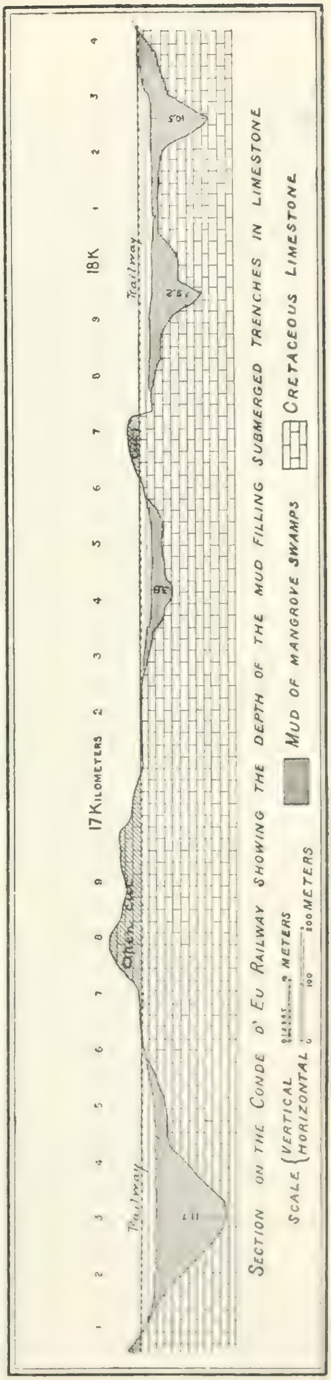
Evidence of the islands. — The process by which islands are formed by depression consists in the lowering of the general land surface until the sea passes up some of the valleys and gets behind or landward of some of the highest points. The island of Itamaracá, for instance, before it became an island, had one stream flowing past its northern end — the Tijucapopo (or Catuáma) — and one flowing past its south end — the Iguassú — and the canal that now separates it from the mainland was a valley through which small streams drained both north and south. When the depression of the coast took place the water backed up into the lower parts of these streams and into the valley behind it, thus entirely cutting it off from the mainland and leaving it an island.

The island of Itaparíca and the other islands in the Bay of Bahia are also the higher portions of irregular land surfaces let down by a depression till the water of the sea flowed round them. Itaparíca channel is a drowned valley that formerly drained northward into what is now the Bahia de Todos os Santos, but which was formerly a valley. The same thing is true of the islands of Tinharé and Boipéba on the coast south of Bahia.

If we wish to test the theory of these islands having been made as here suggested we have but to imagine the effect of an elevation upon them. The deepest water recorded in the channel west of Itamaracá is less than three fathoms. If the land were elevated more than three fathoms evidently this water would run out and we should have a small stream flowing where tide water now enters. Many islands on a coast are usually regarded as evidence of a late depression of that coast. It might be supposed, then, that inasmuch as the Brazilian coast has remarkably few islands, this absence of them might be taken as evidence against a late depression. The islands that do exist, however, bear out the theory of a depression, while the absence of a large number of small outstanding islands bears out the idea that the depression took place long enough ago to allow the sea to obliterate them, and in some instances to throw their remains on the shores of the mainland. These same silts also helped join to the mainland some of the in-shore islands.

Off-shore clays. — The borings made by Sir John Hawkshaw on and behind the reef at Pernambuco in 1874 penetrated to a maximum depth of seventeen metres.[1] The rock of the reef was found to have beneath it beds of sands, shells, marls, and *clays.* Some of the clay beds are more than two metres thick. These clays afford additional evidence of the outbuilding by silts of the formerly indented coast-line. Clays being light, sediments can be deposited only far enough offshore to be out of the reach of the strong in-shore waves. The beach at the time of the deposition of the clays must therefore have been further inland, and the clay beds were buried by later sediments swept seaward as the beach was built outwards.

Evidence of buried rock-channels. — Somewhat in the same line is the evidence of a buried channel discovered by Mr. Samuel H. Agnew, at Parahyba do Norte, on the line of the Conde d'Eu railway. In 1887–8 this railway was prolonged from the city of Parahyba to Cabedello, at the mouth of the Parahyba river, and Mr. Agnew had charge of the construction. Where the line crosses the upper ends of three mangrove swamps immediately northeast of the city station, great difficulty was experienced in carrying the road-bed over the soft mud, owing to its yielding under pressure and allowing the railway to sink. Inasmuch as the largest of these mangues has rock cuts on both sides of it, it was assumed that the mangues had rock bottoms, and accordingly soundings were made



Section on the Conde d' Eu Railway showing the depth of the mud filling submerged trenches in limestone

Fig. 81.

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[1] Melhoramento dos portos do Brazil. Relatorios de Sir John Hawkshaw. Annexos. Rio de Janeiro, 1875.

along the line of the road to ascertain the depth of the mud down to the rock floor. These soundings were taken with steel rods, and the mud was so soft that two or three of the rods were lost by slipping from the hands of the men and disappearing very much as if they had fallen into water. The original profile of the railway, together with rock cuts and soundings across these mangues, was kindly furnished me by Mr. Agnew. They are copied here, beginning with the upper left hand at kilometre 16 from Cabedello.

It will be seen that the mangrove swamp here fills gullies that were cut originally in the hard limestone. The outlines show them to have the form common to stream channels, and as such channels could only be cut when the place was above water level, we are obliged to assume that the land at this place formerly stood enough higher to allow water to flow freely down these gullies. The greatest depth of the mud along the profiles is 11.70 metres, which, added to the depth of water in the mangue above the mud, gives a total depth of at least 12 metres. In order to restore the conditions under which this deepest channel was cut, we must assume an elevation of the land of at least twelve metres. But inasmuch as the railway runs across only the upper or shallower ends of these swamps near the Parahyba hills, it is fair to assume that the main channel of the Parahyba is considerably deeper. Their proximity to the hills likewise precludes the possibility of the channels having been cut by tidal scour.

Additional views of depression. — Shaler expresses the opinion, probably based upon such maps of South America as are available, that the region about the mouth of the Amazon "has recently been lowered to a considerable depth."[1]

Dr. James Geikie says: "The general trend of the coast-line of South America . . . from Pernambuco to the mouth of the river Plate, coincides with the direction of the continental plateau, and may be said, therefore, to have been determined by crustal movements."[2] He thinks the region about Rio has been depressed.

Although Hartt expressed a belief in a recent elevation of the coast, he also refers to evidence of a recent depression. This evidence consists of recent cemented sands covering "drift" clays "down nearly to low tide. This fact seems to prove satisfactorily that formerly the land stood at a higher level even than now."[3]

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[1] N. S. Shaler. Evidences as to change of sea-level. Bull. Geol. Soc. Amer., 1895, VI., p. 162.

[2] James Geikie. Earth sculpture. New York, 1899, p. 332.

[3] Geology and physical geography of Brazil, p. 572.

Inasmuch as the "drift clays" mentioned by Hartt were regarded by him as of glacial origin, he seems to have thought it necessarily a land deposit, and that the coast was submerged since the glacial epoch.

It has been shown elsewhere[1] that there is no satisfactory evidence of glaciation in Brazil.

The "drift" Hartt mentions is probably a part of the water-worn material covering the region lifted from beneath the sea at the close of the Tertiary. It indicates a depression since that emergence.

Hartt also recognized the evidence of the Alagôas lakes, for he says (p. 422): "These lakes of Alagôas, as well as Juparana, are very deep, and their basins must have been excavated at a time when the land stood at a greater height than at present."

Darwin notes the existence of fresh-water Tertiary beds at the head of the Bay of Bahia "now washed by the sea and encrusted with Balini; this appears to indicate a small amount of subsidence subsequent to its deposition." I suppose the idea is that the fresh-water deposits were laid down above tide-level. This may or may not have been the case. The bottoms of the great fresh-water lakes of North America are far below sea-level.

On the island of Fernando de Noronha, two hundred miles northeast of Cape St. Roque, wind-bedded sandstone of recent geologic origin extends beneath the water at high tide.

There can be no doubt about the wind-bedding of these rocks, for in some places the false-bedding dips strongly toward the hills against which they are deposited.[2] The wind-bedding could only be produced above water. This shows that there has been a depression of the land since the sands were deposited.

Élisée Reclus in speaking of the encroachment of the sea about the mouth of the Amazon says that it seems to be due to a general depression of the coast.[3] As evidence of the recent depression of the region about the mouth of the Amazon, Coudreau mentions a large number of enormous stumps in the bed of the little Mapa river on the coast (2° N. lat.).[4]

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[1] J. C. Branner. The supposed glaciation of Brazil. Journ. Geol., 1893, I., p. 753–772.

[2] J. C. Branner. Geology of Fernando de Noronha. Amer. Journ. Sci., 1889, XXXVII., p. 160–161.

J. C. Branner. The æolian sandstones of Fernando de Noronha. Amer. Journ. Sci., 1890, XXX., p. 247–257.

[3] Élisée Reclus. Nouvelle géographie universelle. Tome XIX. Amérique du Sud, p. 146. Paris, 1894.

[4] Henri A. Coudreau. Voyage à travers les Guyanes et l'Amazonie, p. 10–11. Paris, 1887.

Evidences of Elevation.

While the evidences of depression stand out boldly in the topography and geography of the Brazilian coast, — so much so that by an inspection of the maps alone geographers who have never visited the region have been able to interpret them, — yet there are here and there evidences of a late elevation.

This elevation, however, was a feeble one as compared with the depression. Although the uplift was the later movement of the two, the marks of it are not so abundant or so bold as are those of the great depression. The evidence of the elevation is here brought together.

Reference should again be made to what was considered by Capanema and Liais as evidence of an uplift of the Brazilian coast. These matters have already been disposed of on pp. 118 to 125. Unfortunately, out of seven classes of facts brought forward by these writers the only one that has any claim to attention in support of the theory of elevation is one given by Capanema as *islands joined to the mainland*, and possibly that of coastal lakes. But even in these cases islands joined to the land and coast lakes cannot be accepted in support of the theory of elevation unless they have the characteristics of islands and lakes produced by elevation. Islands are joined to the land after depressions as well as by elevations, and coast lakes are formed along depressed coasts quite as readily as along elevated ones. In order to know how islands have been joined to the mainland, and how lakes have been formed, it is necessary to know something of the local geology and geography. In the absence of such knowledge the islands and lakes, excepting the cases already cited, must be left out of the discussion.

The evidence of elevation collected by the author consists of: 1. Elevated sea beaches; 2. Elevated sea-urchin burrows; 3. Death and decay of the coral reefs. These will be treated in this order.

1. *Elevated beaches, State of Alagôas.* — Tatuamínha is a small village on the south side of a river of the same name that enters the Atlantic in S. lat. 9° 16′, State of Alagôas. South of the village a flat bit of country from one to two kilometres wide lies between the Tertiary hills inland and the sea-coast. Mangrove swamps cut into this flat land at several places, but most of it is covered with very calcareous sand containing vast quantities of marine molluscan shells, such as are only found living on the open coast. No note was made of the elevation of this plain above tide-level, but my recollection of it is that it is from one to three metres.

North of Rio Camaragibe (S. lat. 9° 19′) in the State of Alagôas, at a place known as Marceneiro, the following section is exposed on the beach.

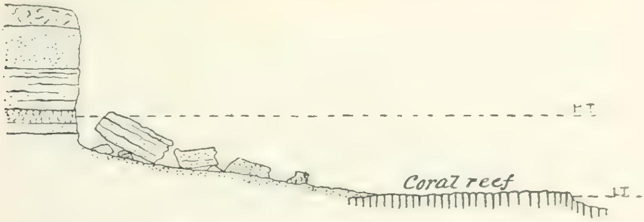

Fig. 82. Section at Marceneiro.

This calcareous rock rises about 2.3 to 2.6 metres above low water, while the total height of the bank amounts to 3.2 metres above low tide.

Elevated beaches, State of Bahia. — In 1879 Richard Rathbun, formerly member of the Commissão Geologica do Brazil, now of the Smithsonian Institution, published an article on the stone reefs, in which he gives a brief description of an elevated beach at Porto Santo, on the island of Itaparíca, bay of Bahia.[1] This description is so important that it is given at some length: "At Porto Santo, there is a curious example of consolidated beach structure, the only instance of the elevation of such material of which we are aware. At this place we find a cliff back of the beach, having a length of about 1,100 feet, and a greatest height of about thirteen feet, and composed almost entirely of sand and gravel, cemented by lime into a sandstone. The lower part of the cliff is very hard in texture, and contains numerous fragments of corals and shells, the latter being frequently found entire. Many of the species of both exist in abundance throughout the bay. The upper part of the cliff is of almost pure sand, and has been so incompletely hardened as to crumble readily between the fingers. The amount of calcareous material in the lower portion is very great, and it is said to yield a good quality of lime on burning.

"Whether this cliff belongs to the same class of structures as the reefs or not, it is, at least, composed of the same materials, and must have been formed in about the same way. Its present elevated position —

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[1] American Naturalist, June, 1879, XIII. 347–358. A somewhat longer article on this same deposit was published by Mr. Rathbun, entitled *A praia consolidada e sublivada e os sambaquis de Porto Santo.* Archivos do Museu Nacional do Rio de Janeiro, 1878, III., p. 172–4.

for high water reaches only slightly above its base — indicates that the shore has been raised at this point to a height nearly equaling that of the cliff. What gives an increased interest to this locality is the presence of a low kitchen-midden, only two or three feet thick, which overlies the entire cliff. It is composed of a dark-colored, sandy earth, packed full of the shells of the edible mollusks of the bay, with a few scattered bones, and occasionally a human skeleton."

When I was at Bahia in August, 1899, Mr. Joseph Mawson directed my attention to important evidence of elevation north of São Thomé on the bay of Bahia, and on the trip to and from that place I was able to collect many other bits of evidence pointing to an elevation of the coast.[1]

The accompanying sketch-map of the region, made on the spot, will serve, in the absence of a better one, to show the topographic relations of the points mentioned. It should be remembered, though, that both the orientation and the distances on this map are only approximately correct.

With the exception of the late beds with which we are especially concerned, the rocks of the region are all folded, faulted, and sometimes decomposed Tertiary sediments.

At the Ponta d'Areia, a point marked A on the northwest corner of the map, there is a flat bit of ground, not more than four acres in area. Half of this flat ground has a sloping sandy beach, and the remainder, in the northeast corner, has a low natural rock wall about 100 to 150 metres long for a water front. This rock lies in horizontal beds, and is made up of shells, corals, and comminuted calcareous matter of various degrees of hardness. The total thickness of the beds could not be seen at the time the place was visited, on account of the tides, but they extend from below high water to about one and a half to two metres above the highest spring tides. The uppermost metre of this is soft sand merging into hard rock below. The surface itself is very black soil to a depth of from fifteen to twenty centimetres, and I suspect it of having a human origin. The material of the lowest part of the beds is of very much ground-up shells and corals.

It is possible that the shells on this point rise to a height of three metres above tide, but those seen on the highest grounds all belong to species that are used for food even to this day, and it is doubtful whether they ought to be included with the elevated beds.

At the point marked B on the map marine shells are strung along

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[1] I am also under obligations to Mr. Richard Tiplady, Superintendent of the Estrada de Ferro da Bahia ao São Francisco, and to Mr. Thomas Mawson, of the same road, for facilitating in every possible way my visit to this interesting region.

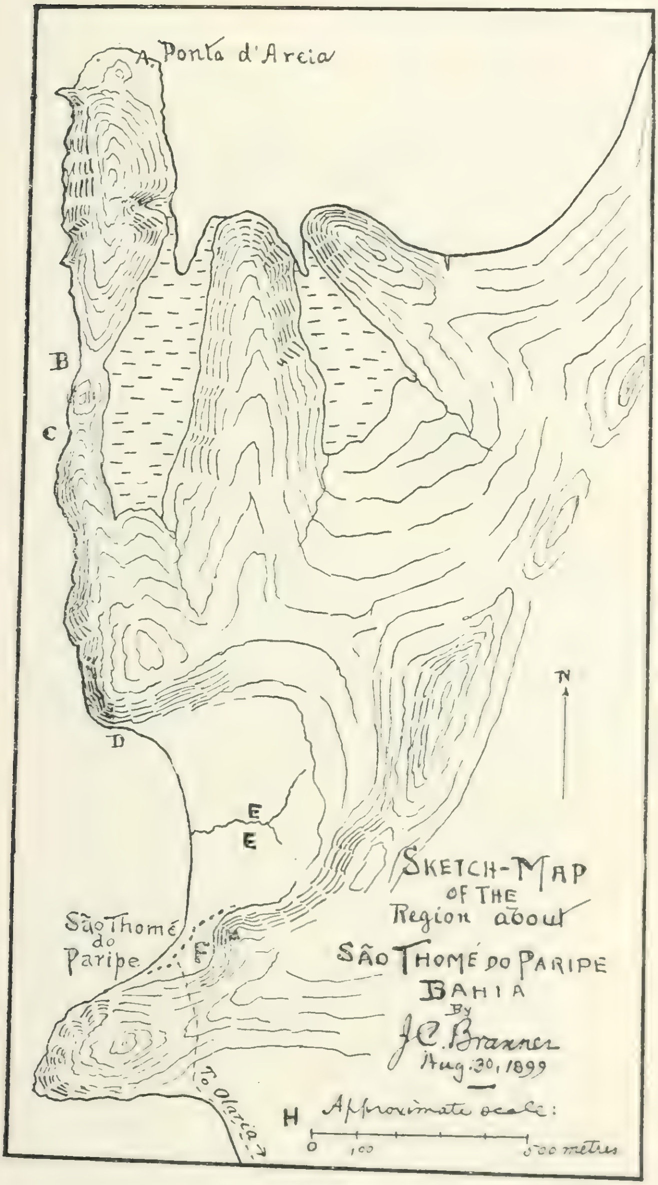
A. Ponta d'Areia
B
C
D
E
E
São Thomé do Paripe
F
H
To Olaria
N
SKETCH-MAP OF THE Region about SÃO THOMÉ DO PARIPE BAHIA By J.C. Branner Aug. 30, 1899
Approximate scale:
0
100
500 metres

FIG. 83.

through a low neck of land at an elevation of 1.2 metres above the highest tides. Between Ponta d'Areia and this place there are many patches of shells along the shores, but they are usually so scattered as to lead one to suspect them of having been left there by human agencies.

At the point marked C on the west side of the ridge a bed of shells extends along the coast at an elevation of from 1.2 to 1.5 metres above tide.

At D on the map the encroachment of the sea has exposed another bit of the elevated beach.

The materials of the old beach are here shells and corals and water-worn pebbles of Tertiary rocks resting upon the upturned and eroded edges of Cretaceous shales and sandstones. Clays from the hills above cover the deposit. The top of the shell bed at this point is one metre above the highest tides.

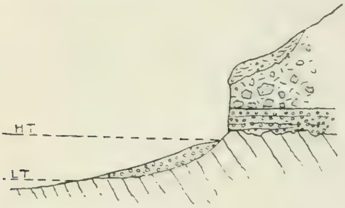

FIG. 84. Section of the beach north of São Thomé.

The valley north of São Thomé is nearly a flat-bottomed one, having a maximum elevation of about 2.1 metres above the highest tides. At the points E a road crosses this valley and descends a gentle slope to cross a small stream. The road on these slopes cuts into a soft rock made of shells like those on the present beach. All over the higher parts of this valley, where burrowing animals have made holes in the soil, fragments of shells have been brought to the surface.

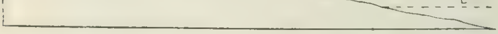

FIG. 85. Section in a gully south of São Thomé.

Yellow calcareous soil with shell fragments	1′–2′
Light gray calcareous soil made of shell and coral fragments . . .	1½′
Dark chocolate brown sand with shell fragments. Color shades off into the brownish gray beds below	8″–16″
Light gray calcareous sand with many loose shells	1′–2′

In the south end of the village of São Thomé and just south of the hill on which the church stands (F on the map) a gully has been washed out in an old road that comes down at right angles to the beach. In this gully the section as shown in Figure 45 is exposed.

Twenty metres back from the beach the tops of these beds are about 2.1 metres above the highest tides.

All over the two mangrove swamps shown on the map the crabs have brought up from their burrows fragments of beach forms of mollusks — shells of species that do not live in mangrove swamps.

Before leaving São Thomé it is worthy of note that the shells occur on the beach in front of the village in an almost incredible abundance. There is at this village a considerable industry in the manufacture of lime, all of which is made of the shells raked up on the beach.

Just north of Olaria station on the Bahia railway, and in the outskirts of that village (H on map), is a small stream called the Tubarão. Where this stream enters the bay, and on its north bank, there are hardened beds of shells. They reach an elevation of a little more than one metre above the highest tides.

Some 300 or 400 metres south of Olaria station the Bahia railway crosses a small bridge. About fifty metres east of the track at this bridge the shell beds are a little more than one metre above high-tide level.

Periperí on the Bahia railway stands in a semicircular, flat-bottomed valley very like that at São Thomé, and the sands of its floor contain an abundance of marine shells. I do not know the elevation of this valley floor, but it is low — not exceeding three or four metres.

Marine terrace at Ilheos, Bahia. — The evidence at Ilheos consists of terraces. One of these — the Opába terrace — is about a kilometre north of Ilheos, and 300 metres back from the present beach. It lies across the mouth of a small steep-sided valley of which a sketch-map is given here (Fig. 86).

The rocks of the hills on both sides of this valley are crystalline — gneisses cut by dikes of diabase,[1] and decayed to red clays at the surface. Above the terrace is a marsh, and below it a shallow fresh-water lake. The terrace itself is about 120 metres wide at the base, from 150 to 160 metres long, and 7.31 metres high. It has a steep front or downstream face — 40° and more — while the upper face slopes back very gradually to the marsh. The material is all loose, light-brown, coarse

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[1] One of these eruptives was kindly examined by Mr. H. W. Turner, late member of the U. S. Geological Survey, and found to be a good typical diabase composed of basic feldspar, monoclinic pyroxene, and magnetite.

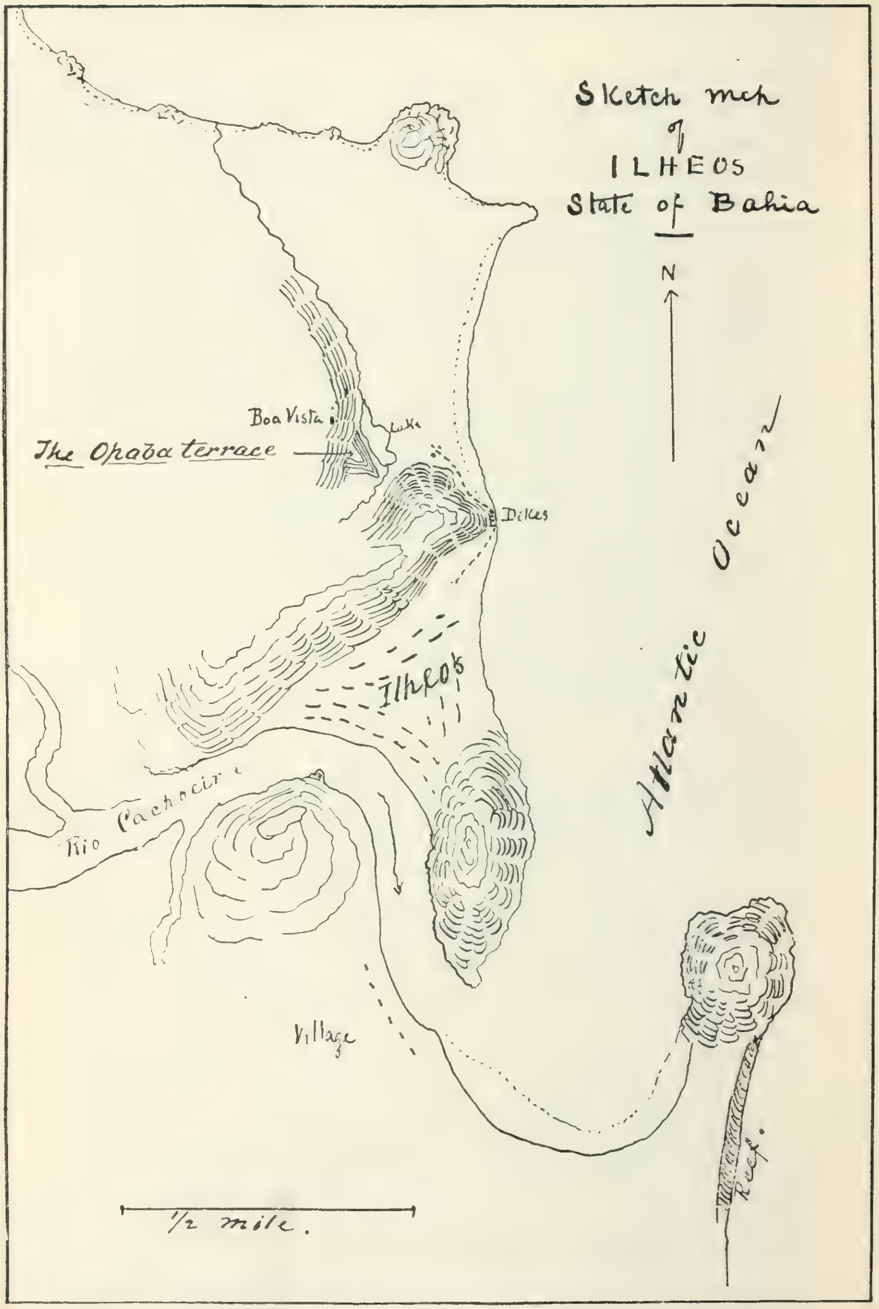
Sketch map
of
ILHEOS
State of Bahia
N
Boa Vista
Lake
The Opaba terrace
Dikes
Ilheos
Atlantic Ocean
Rio Cachoeira
Village
Reef.
1/2 mile.

FIG. 86.

quartz sand; some of the sand grains are as big as peas. No shells were found over the surface save recent land shells.

A hundred and fifty metres north of the terrace a small fragment of soft sandstone, in texture very like the sand of the terrace, lies against the schists of the hill at about the same elevation as the terrace. The photograph of the terrace was made from this point (Plate 69).

This Opába terrace is the only one examined at Ilheos, but there are other terraces in the vicinity at about the same elevation as this one, and probably of the same age. These are mentioned here rather for the purpose of putting them on record for future observers than as evidence that can be trusted without further examination.

About three kilometres north of Ilheos, on the beach at a place called Vellosa, is a terrace apparently about the same height as the Opába terrace. The Vellosa terrace is a noticeable feature when seen from the sea as one approaches Ilheos from the north. It appears to be about half a kilometre long, is perfectly flat as seen from the front, and has the drainage from behind it coming round its south end. It stands across the mouth of an embayment and is covered with coco palms.

A photograph was taken of this terrace from one of the rocky points a kilometre to the south (see Plate 70).

Southwest of the town of Ilheos, on the opposite side of the river, is a hill shown on Mouchez' chart of this port. At the extreme northern end of the hill there seems to be a remnant of a terrace, while half a kilometre further south on the side of the same hill traces of the same terrace are visible. I do not doubt but that if they were uncovered these terraces might be traced a long way up and down the coast, but the jungle-covered, uncultivated condition of most of the region makes it impossible to get more than a mere glimpse of them here and there.

Lagôa de Itahýpe. — Spix and Martius mention what appear to be elevated beaches in the vicinity of Ilheos.[1]

"Banks of sea-mussels appear not only on the mainland, but to greater extent on the sea-coast. The shells belong to none but living marine mollusks, as *Ostrea edulis*, species of *Tellina* and *Fasciolaria*. They are usually only slightly altered. Often the cement or sea-sand so predominates that this still constantly growing formation can be used as building material; if, however, lime predominates, lime is burned from it. . . . The presence of these mussel banks, as well as the coral distant so many miles from the coast, and the entire formation of the land on this large plain, seem to signify that the sea has retreated here more and more, and the products of its waters gradually surrendered to the firm land."

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[1] J. B. Spix u. C. F. P. von Martius, Reise in Brasilien. Vol. II., note on p. 710. München, 1828.

At Ponta d'Areia, Bahia. — Ponta d'Areia, the terminus of the Bahia e Minas Railway, stands on a sandy flat that reaches from the sea at the Barra de Caravellas up the river to the old city of Caravellas — a distance of five kilometres. Following the line of the railway this same sandy plain continues to kilometre ten. This much of it I have examined, but the configuration of the country suggests that this sandy plain extends far up and down the coast — possibly as far as Prado.

At Ponta d'Areia the plain has a maximum elevation of only 2.29 metres above high tide; near Barra de Caravellas it is from 2.5 to 3 metres, and at the city of Caravellas it is from 2 to 2.05 metres above tide. The profile of the railway is not available, otherwise the elevation of the landward margin of this plain might be given.

This plain is not hummocky like a sand plain heaped up by winds upon a growing beach, but is characterized by long gentle slopes that are imperceptible to the eye, and by sudden changes of level like the materials of a sand bar.

The upper part of these sands is generally of a grayish color darkened with organic matter, while at a depth of 0.2 to 0.4 metres they are of a yellow, almost an orange, color.

I have spoken of these beds as sands: on top they generally are sands, but at a depth of a metre or so they are often sandy clays, so much so that they are used for making pottery, bricks, and tiles. I have not seen any false bedding in this formation.

Everywhere over the plain these sands contain an abundance of marine shells both entire and broken. They are brought to the surface by ants and other burrowing animals, and are found in the shallow railway cuts, in post-holes, and in wells.

At one place between Ponta d'Areia and Caravellas in this formation I found also a piece of coral (*Heliastræa aperta*) as large as one's fist. I am not, however, without doubt about trusting this coral fragment. It was found within 300 metres of Pitonga, a little village of three or four cabins, and may have been dropped here by man. It is of a species used for making lime.

At another place half-way between Ponta d'Areia and Barra de Caravellas I found in the debris thrown from a shallow pit dug in search of water one small specimen of coral (*Astrangia solitaria*). This specimen

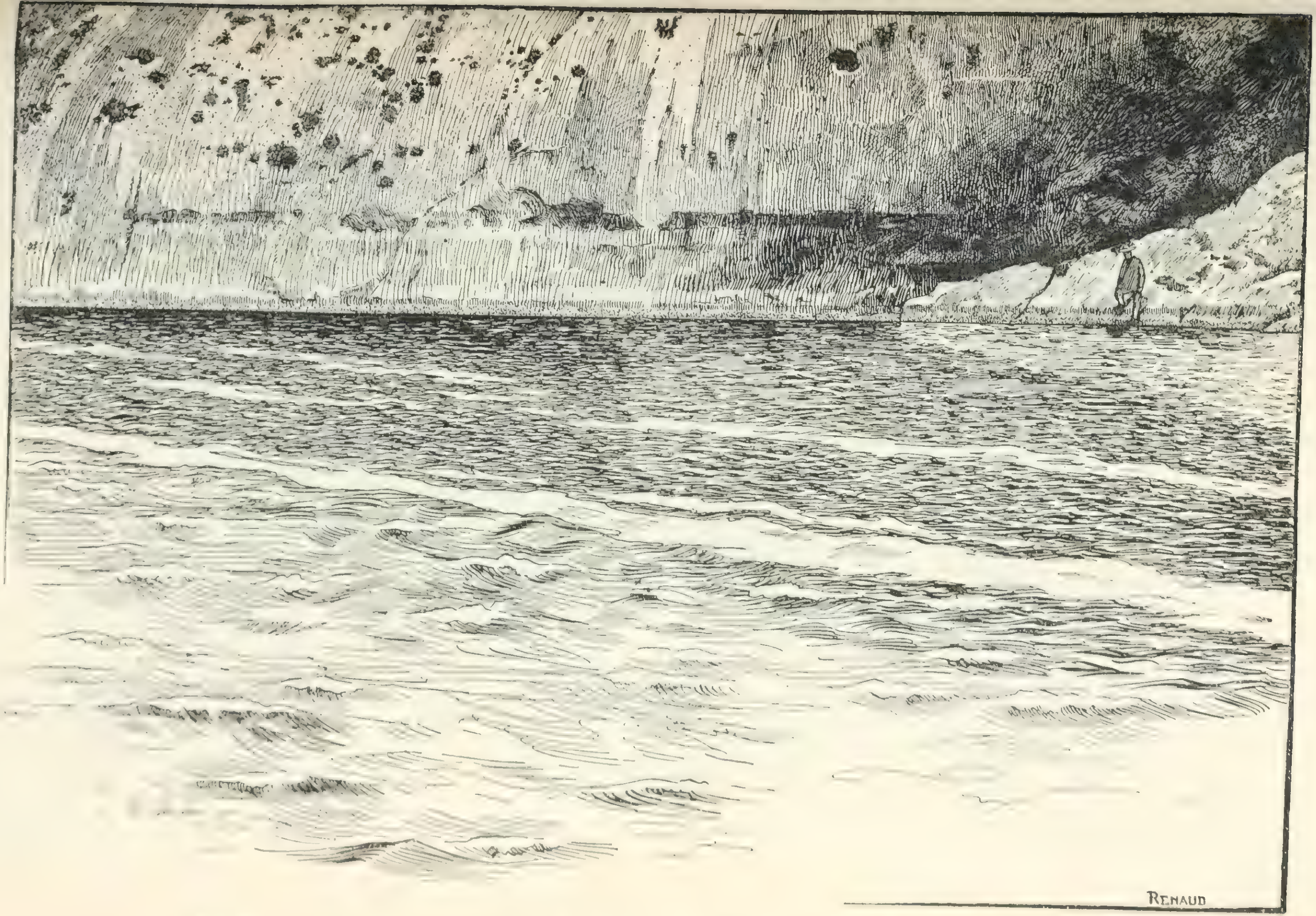

Fig. 87. Ancient water line at Victoria. From a photograph taken from a passing steamer.

was found under circumstances that place it quite beyond any doubt about its belonging where it was found.

The shells have the general aspect of the shells of the present coast, but I am disposed to think this an altogether too off-hand way of dealing with them. I am not at all sure that a careful study would not find a considerable difference between the fossil fauna of the sand plain and the existing off-shore fauna.

Shells may be left over a plain by the seaward extension of the shores, or by the elevation of the sea-bottom. Inasmuch as this plain stands from one to three metres above the highest tides, and as it is not wind-bedded but is made up of horizontally bedded clays and sands filled with recent marine shells, we must admit a recent elevation of at least three metres to account for it.

At Victoria, Espirito Santo. — Hartt long ago spoke of the evidence of elevation on the island of Maricá, off the coast between Rio de Janeiro and Cape Frio,[1] at Sant' Anna, and at Victoria, Espirito Santo. In 1899 I visited Victoria again and examined some of the evidence he found there. This evidence consists of a horizontal line of open-mouthed pits or depressions only a few centimetres deep but yet perfectly well defined, and about one metre above the highest tide-level. This line is most clearly shown on the big exfoliated peak formerly called the Pão d'Assucar, but now generally known as the Penedo. The same sort of a line shows at several other places in the vicinity, notably on a big block about four hundred metres further down the river, but always at the same level. Hartt thought this line "evidently worn by wave action within comparatively recent times." I am not sure what made the line, but I am confident that it is due to a change of water-level. The pits are not such as are made by sea-urchins, and I found nowhere on these rock-faces or elsewhere similar lines worn by waves. The only explanation that seems to be satisfactory is that they have been formed since the elevation of the coast by the weathering along a line of partial decomposition brought about by the effect on the rock of organisms that once grew along that line.

I have examined the line of organic growth near mean tide and low tide levels at many places along the Brazilian coast, and I am disposed to think that the line of pits on the Victoria rock correspond with the low tide line of seaweeds, barnacles, and Serpulae — the line where these things seem best to thrive. There is no proof of this, however. It is simply an inference based upon the supposition that these organisms would affect the rock along the line where they grow.

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[1] Geology and physical geography, p. 36, 42, 71–72.

2. *Elevated sea-urchin burrows.* — The boring sea-urchins of this coast (*Echinometra subangularis*) can live in places where at low tide the waves break over them occasionally, or they can live in tide-pools. But so far as I can learn they do not live in places where they are completely uncovered at low tide.

A few kilometres north of Cabo Santo Agostinho, at a point of land known as *Pedras Pretas* are many exposures of a massive black trachyte upon the sea beach and rising in the hills above. There are three or more places where these trachyte masses in place are bored by sea-urchins. These rocks, and one other and larger exposure, are in place, while a third one may possibly be a loose block. The parts bored with these holes are *between high and low tide levels.* As will be seen from the illustration the exposures of these bored faces are such that it does not seem possible that sea-urchins could live in them if uncovered even at low tide.

Of the several exposures of such borings at this Cape not one is found beyond the reach of high tide. To put these holes all below low tide would require a depression of two metres.

It should be added that no such holes were found in the granites exposed at Pedra do Porto and Pedra do Conde in the southern part of the State of Pernambuco a short way north of Rio Una, but on Cabo Santo Agostinho on the south side of the Cape and west of the sand reef there are a few holes in the granites between tide-levels that look as if they might have been made or partly made by sea-urchins.

3. *The death and decay of the coral reefs.* —The decay and erosion of the upper surface of the stone reefs I have not seen mentioned as evidence of elevation. The illustration given herewith shows a characteristic fantastic form common upon the stone reefs of the coast. These forms have the bedding of the original sand layers distinctly preserved and there can be no question about their being the remnants of upper beds that have been removed by erosion. This erosion, however, may have been produced either by the ordinary processes of weathering and removal by the waves, or it may have been the work of the surf. The form here represented is still quite within the reach of the surf at high tide. These forms cannot therefore be accepted as evidence of elevation. I do not, however, feel so confident in regard to the meaning of the decay of the upper portion of the coral reefs of the coast. I know of no reason why the stone reefs may not have been consolidated at any elevation at which they are now found. But in the case of the coral reefs the rock can be

formed only where the living polyps and other reef builders are always covered by water. This does not necessitate their always being below low tide level, for corals grow constantly in tide-pools, and Serpulae often build up rims enclosing basins whose surfaces are left several feet above low tide. In such basins corals may flourish above sea-level. But while these cases are not at all uncommon, the area covered by them, when considered in relation to the whole area of the coral reefs of which they form part, is very small indeed.

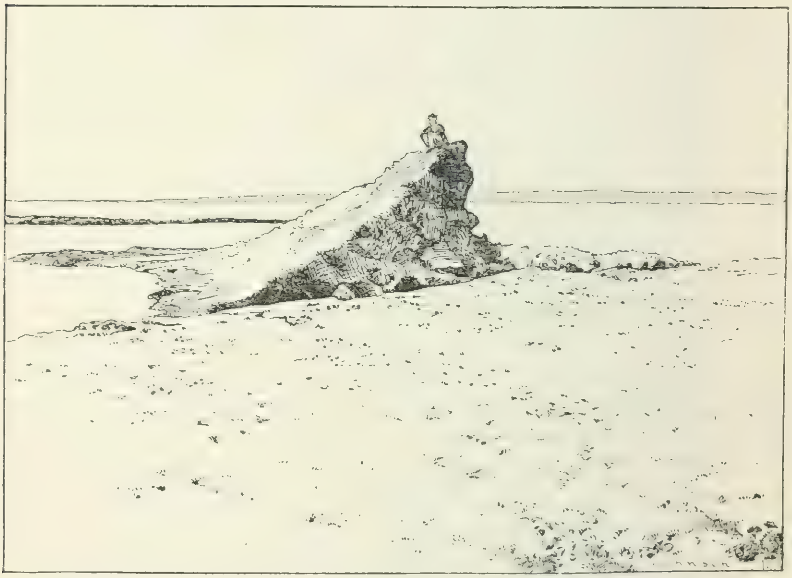

FIG. 88. High Rock, Maceio coral reef. From a photograph by F. Ambler.

Along the entire coast from Parahyba do Norte to Parcel das Paredes, the Abrolhos, and Corôa Vermelha, the coral reefs not only rise above low tide water over enormous areas, but the upper surfaces of all these exposed reefs are dead, excepting in so far as they are made of such things as grow in tide-pools. In the north the coral reefs are universally bored by mollusks, sea-urchins, etc., and for the most part have an etched appearance.

In the State of Alagôas, three kilometres south of São Miguel dos Milagres and north of the Rio Camaragibe, there are exposures, at low tide, of coral reefs upon the sandy shore. At the mouth of a small stream the reef has been covered by sand, and later it has been again uncovered by the shifting of the currents. The coral reef surfaces are usually so blackened with corallines and other growths that the structure cannot be seen, but at this place it is shown perfectly. Heads of *Porites* and other corals are cut through and partly eaten away either chemically or mechanically. At low tide these reefs are exposed for half a kilometre out seaward. Nearly one kilometre south of the beach exposure just mentioned is another place where the beach sands overlie a dead coral reef. The photograph given herewith was taken at the last-named place. It shows not only the in-shore reef but two other coral reefs further out: the further of these is nearly one kilometre from the shore.

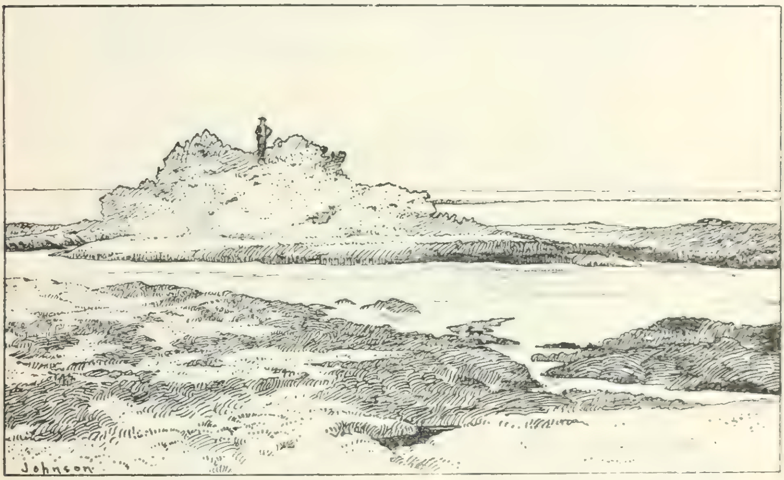

FIG. 89. High Rock, Maceio coral reef. From a photograph by F. Ambler.

In this connection mention should be made of a mass of coral rock on the reef at Maceio. The Maceio reef is of coral, is three kilometres or more in length, and varies in width from a few paces at certain points to nearly a kilometre at its northern end, where it joins the sandy beach. At one point east of Jaraguá a solitary mass of coral rock rises three metres above the general level of the coral reefs. There is no other such rock on the Maceio reefs. It was formerly supposed that this was the remnant of an old reef that had been cut away by the waves. The accompanying illustration made from a photograph kindly obtained for me by Mr. F. Ambler of the Alagôas Railway Company at Maceio shows that this mass is simply a tilted fragment of the reef thrown into its present position by having been undermined at one end.

Time Relations of the Elevations and Depressions.

Having presented evidence of both an elevation and a depression, it remains to determine the order of these movements.

Inasmuch as the elevation recorded appears to have been a comparatively small one, two orders are possible: —

1st. An elevation greater than the one here described, followed by a depression that returned the elevated coast to within a few metres of its original position.

2d. A larger depression followed by a smaller elevation.

These two assumed orders of events can be tested by a process of elimination by trying to explain thereby the conditions known to exist.

A section across one of the mangrove swamps shown on p. 150 is given herewith: —

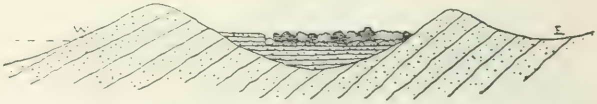

Fig. 90. Section across a mangrove swamp near São Thomé.

Case I. Section across the north of São Thomé, mangrove swamp and shell beds. See pp. 149–152.

Hypothesis I.	*Hypothesis II.*
1st. Greater elevation.	1st. Greater depression.
2d. Smaller depression.	2d. Smaller elevation.
The elevation would allow the erosion of the shell beds; the depression would admit mangroves into the subsequently drowned valleys. This requires that the shell beds be first deposited, which of itself requires a still earlier depression.	The shells are deposited during the depression; the small elevation brings them up where they are now being eroded. In the swamps, the shallow bay bottom is brought up within reach of the plants.

Case II. Section across the São Thomé valley. See pp. 149–152.

Hypothesis I.	*Hypothesis II.*
The earlier elevation would have to assume the shell bed already formed, in which case the elevation would leave it to be eroded and depressed again.	The greater depression would allow the shell bed to be formed after the depression, and slightly elevated later.

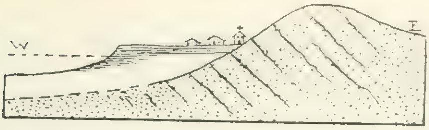

FIG. 91. Section at the village of São Thomé.

CASE III. Trachytic boulders (see p. 159).

Hypothesis I.	*Hypothesis II.*
The burrows would have to be made before the greater elevation, and the following depression would bring them within the reach of the water.	The rocks were carried beneath the water by the depression, then burrowed, and later slightly elevated.

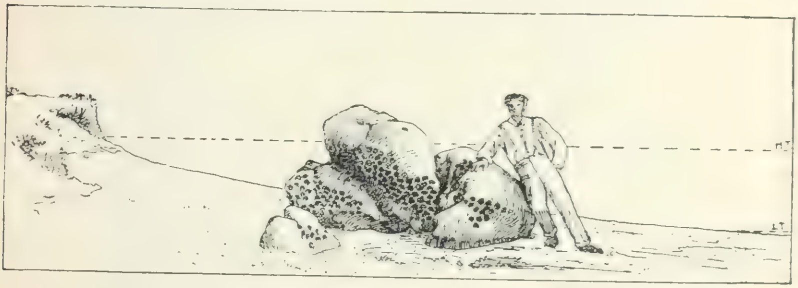

FIG. 92. Trachyte blocks bored by sea-urchins.

CASE IV. has reference to the eroded coral reefs (see pp. 239–245).

Hypothesis I.	*Hypothesis II.*
Greater elevation would either have to take place before the reefs were made, or else the reefs would all be killed by the elevation. The depression would put them back in the water.	The depression would permit corals to grow up to a depth of 150′; a small elevation, when they were already near the surface, would kill them and allow them to be eroded.

CASE V. is that of the terrace at Ilheos spoken of on pp. 153–155.

Hypothesis I.	*Hypothesis II.*
Necessitates the formation of the terrace before the elevation, and a subsequent depression.	The terrace was made during the depression, and lifted by a small elevation.

These cases all appear to favor the second hypothesis. It is a very noticeable feature of the first hypothesis that it requires still earlier movement and time for the formation of the deposits, while the second hypothesis satisfactorily accounts for all the deposits with only two movements.

Taking the case of the São Thomé valley the sequence is also satisfactorily established. A glance at the region shown in the sketch map on p. 150 shows that it has had the following geographical history: Subsequent to the deposition of the Tertiary beds, these rocks were compressed more or less, lifted out of the water, and subjected to decomposition and erosion that carved out rather steep-sided valleys. There then followed a depression that admitted the water into the whole region now covered by the Bay of Bahia — *and a little more.* The upper ends of these valleys began at once to silt up with sands, shells, and the like. After they were already considerably shoaled by this process, there came a slight elevation that brought the shallow ends of these valleys out of the water, and left them exposed on their margins here and there to the action of the waves.

Thus the second hypothesis of a larger depression followed by a smaller elevation appears to fit all cases, and for the present at least must be considered as the correct one.

Influence of the coral reefs. — A factor that has been an important one in controlling the outlines of the northeastern Brazilian coast is the coral reefs. Their influence has been both protective and constructive. There are included under this head, not only the corals proper, but likewise the Serpulae and other lime-secreting organisms that live attached to the rocks and reefs. Without such protection, the stone reefs themselves would probably long ago have been obliterated.

The forms of the shores behind the reefs stand in evidence of the great influence of the reefs upon these shores. Wherever there is a reef of considerable length, a sand spit reaches out from the land to meet it. Unfortunately the coast charts are not sufficiently detailed to show this. On the ground it *saut aux yeux.*

The small harbors south of Pernambuco nearly all open behind breaks in the reefs. That at Tamandaré is an example. North of the bay the point on which Tamandaré stands approaches the coral reef north of a break, while Ilhetas Point approaches it in the same way south of the break, leaving the bay a semicircular one.

Maceio is another example, though in this case the harbor is behind one end of the reef.

The coral reefs have already caused a general advance of the shores toward the sea, and in time the space between the reefs and the shores must be closed, even without any alteration of level of the coast.

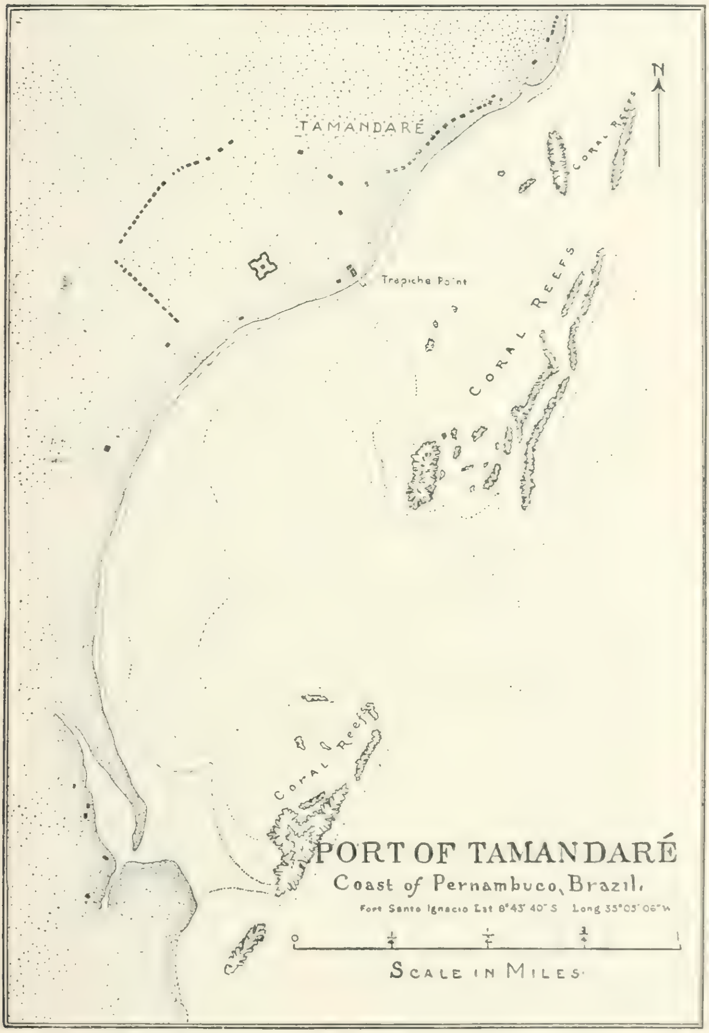
TAMANDARÉ
N
Coral Reefs
Trapiche Point
Coral Reefs
Coral Reefs
PORT OF TAMANDARÉ
Coast of Pernambuco, Brazil.
Fort Santo Ignacio Lat 8°43' 40" S Long 35°05' 06" W
0
1/4
1/2
3/4
1
Scale in Miles.

Fig. 93.

It is a well-known fact among engineers that when headlands appear above water, they are attacked by the waves, but at the same time they cause a seaward advance of the shores behind them. This is well illus-

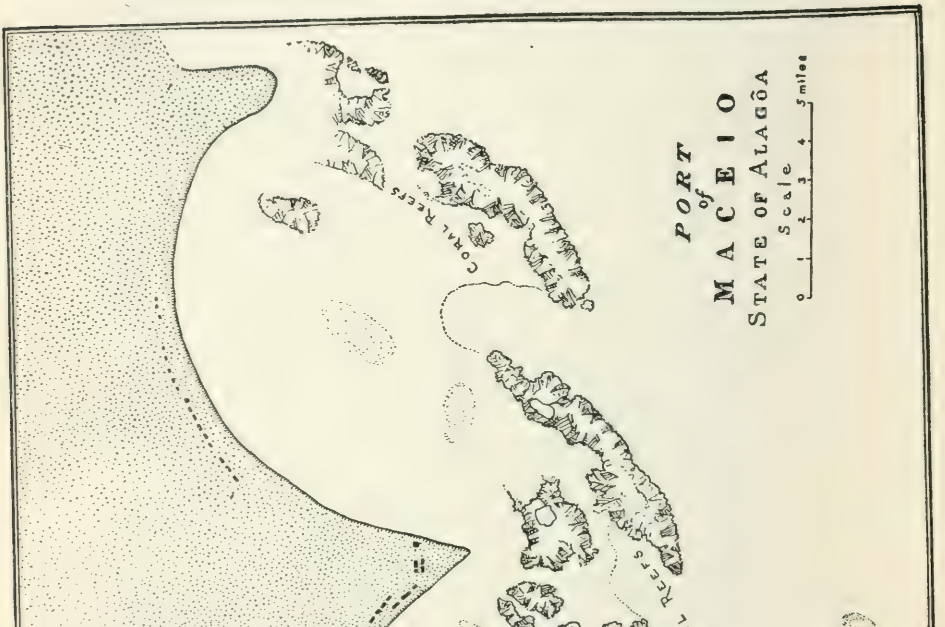
PORT
of
MACEIO
STATE OF ALAGÔA
Scale
0 1 2 3 4 5 miles
CORAL REEFS
CORAL REEFS
Village of Juragua
MACEIO
N

FIG. 94.

trated by the behavior of the silts about any extension of jetties about harbors.[1]

Influence of the mangues. — The various forms of tide-marsh vegetation, especially the mangrove swamps, have played an important part in the turning of shallow waters into marshes, and later into land. So far as I have observed, the mangrove plants thrive only on new and growing land deposits. The plants are influential in preventing scour by the tides, and in holding the silts and other accumulations together until they can be seized upon by other plants. Their wide and ever-spreading roots, the new plants started both from seeds and from roots, the protection they offer to various forms of amphibian life, make of these mangroves a geologic agency of the first importance in the tropics on the borderland between fresh and salt water — between land and sea. Most of the mangrove plants one sees near the streams are only from three to five metres high. At Cannavieiras, however, there are enormous forests of mangrove-trees from fifteen to twenty-five metres high, and with large straight trunks rising upon their straddling roots.

Hyacinths. — In fresh waters the water hyacinth, known in Brazil as *Baroneza*, is an important geologic agent, choking up streams and lakes, depositing organic accumulations over the bottoms of these water bodies, and even drifting out to sea, especially during the rainy season, in enormous quantities.

Origin of the coast sands. — It is not altogether germane to the present discussion to consider the origin of the sands that form the dunes and beaches of the northern coast of Brazil, and the subject would not be referred to here if there were not erroneous theories current regarding these sands. I have heard it maintained and have seen it stated that they were brought to Brazil from Africa by the equatorial currents;[2] and also that they come from the Amazonas. Barão de Capanema thinks the sands of the coast of Ceará come from the Serra do Araripe.[3]

The carrying of the sands across the deep Atlantic is altogether out of the question. Streams are unable to carry any but light sediments across deep portions of their channels, to say nothing of the South Atlantic current that moves at a rate of from one to two kilometres an hour, for four thousand seven hundred kilometres, and has a maximum depth of more than four kilometres.

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[1] See cases of Calais and Dunkirk. Harbours and estuaries on sandy coasts. By L. F. Vernon-Harcourt. Proc. Inst. Civ. Engs., 1881–2, LXX., p. 3, 6.

[2] Thomaz Pompeo de Souza Brazil. Berthot and Moreau de Jonnes in Ensaio Estatistico da Provincia do Ceará. p. 13, 49, 1863.

[3] Trabalhos da Commissão Scientifica de Exploração. I. Introducção. CXXXV. Rio de Janeiro, 1862.

Mention may also be made in this connection of the fact that the Atlantic basin between West Africa and Brazil contains no materials of direct land origin except near the continental shores. The deep sea bottom is covered elsewhere with red clay and organic (Globigerina) ooze.[1]

As to the possibility of Amazonian sources, the question is one of the shore currents and winds. But the currents along the northern coast of Brazil set westward and northward, and unless there are in-shore return currents, the sands brought down by the Amazonas cannot travel southeastward. Besides, the methods of discharge of the streams north of Cape São Roque (all of them bend northwestward and follow the coast) indicate that the sands of the coast are moving northward rather than southward.

The accompanying map showing the relief of the sea-floor out to the 100-fathom line has been constructed by drawing in contours from the data on the hydrographic maps of the northeast coast of Brazil. This map shows that the continental margin lies from 25 to 35 miles off the present shore. Over this shelf the water is rather uniform in depth. The clean-cut shoulder about Cape St. Roque, where the eastern equatorial currents strikes it, and the gradual outward slope of this shoulder toward the north, seem to suggest that the north-flowing current sweeps in that direction the materials cut from the shores.

The fact is, that in the main the sands of the coast are of local origin. They have simply been cut from the headlands and thrown back into embayments, until the embayments were filled up, after which the encroaching sea has attacked these sands themselves and thrown them upon the beaches, whence, when dry, they are swept up inland by the on-shore winds that blow here the year round. The corallines, reef-building corals, and other lime-secreting organisms have also contributed enormously to the recent sands of the coast, while the streams have all brought down more or less sand from the land. An examination of the sands made in June, July, and August, 1899, bears out this theory in every detail. Along shores having corals reefs, the beach sands are calcareous; where the coast rocks are granites, gneisses, or schists, the sands are made of the minerals composing those rocks. The sands of the beach opposite the island of Santo Aleixo are different from the sands found anywhere else on the coast, but the rocks of Santo Aleixo are different from the other rocks along the coast. A microscopic examination of the Rio Formoso reef rock shows that the sand is derived from granites or gneisses, — just such rocks as lie to the landward of the narrow strip of Tertiary sediments that form the immediate coast at that place.

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[1] Challenger Reports. Deep-Sea Deposits. Chapter I. London, 1891.

The theory of the transatlantic origin of the Brazilian sands seems to have had some support from Élisée Reclus, who puts forward the equally remarkable theory that the sediments swept into the Atlantic by the Amazonas are deposited upon the coast of Georgia and the Carolinas.[1] In such a case the Amazonian silts would have to cross some of the deepest places in the Atlantic Ocean, to say nothing of the flocculating and precipitating influence of salt-water upon these sediments.

Conclusions regarding Coast Changes.

1. There is no evidence of a perceptible change of level of the coast since the discovery of Brazil.

2. Changes have taken place in the form of the coast-line, and in the adjacent streams, bays, and estuaries in historic times, but they are all accounted for by the ordinary processes now in operation.

3. The stone reefs are not metamorphosed or folded, and they do not rise above tide-level, except in a few instances, where blocks have been tilted by the undermining done by the waves.

4. The coast lakes have been formed by the damming in of estuaries, by the sands blown along the coast, and by the throwing back into the estuaries of detritus cut by waves from adjoining headlands or brought down by streams from the land.

5. The straightness of the coast-line is due to the long period of wearing to which the coast has been subjected, and to the constant on-shore winds and waves along the coast.

6. During the dry season the waves of the sea are able to close the mouths of many of the weaker streams.

7. At such times only the large streams are able to keep their mouths boldly open.

8. Although no changes of level are known to have taken place within the historic period, there are evidences of both elevation and depression of the Brazilian coast in late geologic times.

9. The evidences of depression consist of: —
   a. The open bays: Rio de Janeiro and Bahia.
   b. The partly choked up bays, such as Santos and Victoria.

---

[1] Élisée Reclus. Nouvelle géographie universelle. Tome XIX. Amérique du Sud, p. 146–147, Paris, 1894.

c. The coast lakes formed by the closing of the mouths of estuaries such as Lagoâ Manguaba, Lagoâ do Norte, Jiquiá, Sinimbú, etc.

d. Embayments altogether filled up.

e. The islands along the coast are nearly all close in-shore and have the appearance of having been formed by depression of the land.

f. The buried rock channels at Parahyba, now filled with mangrove swamps and mud, show a depression of at least twelve metres since those channels were cut.

g. Wind-bedded sand below tide-level on Fernando de Noronha.

10. The evidences of elevation consist of: —

a. Elevated sea beaches especially well shown about the Bay of Bahia, and along the coast of the State of Bahia.

b. Marine terraces about Ilheos in the State of Bahia. These are about eight metres above tide level.

c. Horizontal lines of disintegration about one metre above high tide in granites and gneisses at and about Victoria, State of Espirito Santo.

d. Burrows of sea-urchins so far above low tide that sea-urchins can not now live in them. These are well shown at Pedras Pretas on the coast of Pernambuco.

11. Of the two movements the depression has been much the greater and was the earlier.

12. The great depression probably took place in early Pliocene times. (See the chapter on Geology, pages 8 to 33.)

13. Following the Pliocene depression of the coast, the headlands were strongly eroded, the mouths of bays and estuaries were closed, and the coast line straightened.

14. The sandstone reefs of the coast were formed and hardened subsequent to the depression.

15. The coral reefs of the coast have helped build out the shores, and they have likewise protected the land from the destructive action of the waves.

16. The stone reefs have also protected the land, and have helped to prevent the encroachment of the sea.

17. The mangrove swamps have been important agents in building up the newly formed land about estuaries and embayments.

18. The sands of the coast are not of foreign origin, as has been surmised, but are derived from the adjoining headlands, or they have been brought down from the land by streams.

VI.

The Consolidation of the Stone Reefs.

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Having studied the forms and origin of the beaches, we may now consider the process or processes by which they may have been consolidated.

That the ancient forms of the beaches of which the stone reefs are made have been preserved is due to the fact that the sands of these beaches have been firmly cemented. Without the hardening, we should have had no stone reefs, because the processes of beach changes would have failed to leave these old shore lines outstanding: they would either have been buried by later accumulations, or have been destroyed by wave action.

The Cement.

The hardening of the rock is due to the deposition of carbonate of lime in the interstices of ordinary beach sands. This is shown by a microscopic examination of fresh specimens of the rock (see page 173), and by putting a piece of the rock in an acid that will remove the lime carbonate.

A chemical analysis has been made of a sample of the Rio Formoso reef rock, with the following results: —

ANALYSIS OF ROCK FROM THE STONE REEF OF RIO FORMOSO,
R. N. BRACKETT, ANALYST.

Specimen dried at 110° *to* 115° *Centigrade.*

	Per Cent	Per Cent
Matter soluble in concentrated hydrochloric acid		35.94
Matter insoluble in concentrated hydrochloric acid		64.06
Silica (SiO_2) (nearly all quartz sand)	63.52	
Alumina (Al_2O_3)	0.39	
Iron (Fe_2O_3)	0.36	
Lime carbonate ($CaCO_3$)	29.65	
Carbonate of magnesia ($MgCO_3$)	4.97	
Phosphoric anhydride (P_2O_5)	trace	
Magnesia (MgO)	0.18	
Potash (K_2O)	0.21	
Soda (Na_2O)	0.28	
Loss on ignition	0.39	
Total	99.95	100.00

The analysis shows a rather high percentage of lime, but this lime does not all come from the hardening material between sand grains. The rock contains many pieces of shells, corals, and other calcareous fragments, in addition to the lime deposited between the sand grains; it is not possible to entirely remove all of these shell fragments from the material used in the analysis.

An analysis was made by Prof. L. R. Lenox of the binding material of the Mamanguape reef rock. In order that the results of this analysis may be compared with that of the Rio Formoso reef rock, the two are put here side by side.

ANALYSES OF THE BINDING MATERIAL OF STONE REEFS.

	Rio Formoso rock.	Mamanguape rock.
Lime (CaO)	16.60	17.59
Magnesia (MgO)	2.55	2.58
Equivalent to carbonate of lime ($CaCO_3$)	29.65	31.41
Carbonate of magnesium ($MgCO_3$)	4.97	5.39

There is, therefore, a striking similarity in the binding materials of the two rocks, though the specimens came from reefs more than two hundred kilometres apart.

The hardening of the rock has been produced by the deposition of lime carbonate and magnesium carbonate in the sands. When placed in acid, the carbonate is soon dissolved, and the sand grains fall apart; second, a microscopic examination of thin sections of the rock shows that the spaces between the sand grains are filled with carbonate of lime, and sometimes with a little hydroxide of iron. At a few places the hardening is caused by iron, but these instances are purely local.

It is pointed out in the chapter upon the coral reefs that, when dead coral skeletons are left for a long while saturated with sea-water, some of the lime is replaced by magnesia and that ultimately a dolomite or a dolomitic limestone is formed. It is not known at present whether a similar change takes place in the binding material of the rock of the sandstone reefs. It may be that the original binding is what we find it to be at present, namely, a dolomitic lime rock, or it may be that the original binding material is carbonate of lime, which is partly replaced by magnesium carbonate from the sea-water.

THE MICROSCOPIC EXAMINATION OF THIN SECTIONS OF SANDSTONE FROM THE RIO FORMOSO REEFS.[1]

Thin sections of these sandstones show in general, under the microscope, a rock made up of irregular grains of quartz and organic fragments cemented together with calcite. (Nos. 1, 2, 3, 5, 6.)

The proportion of quartz to organic fragments varies within considerable limits in different sections. Besides the quartz, there are a few irregular sections of a feldspar, probably orthoclase, as well as some brown matter, which appears to be hydroxide of iron. Many of the quartz grains are grown through with fine dark and light colored needles, which may be rutile. Bright, strongly refracting, brilliantly polarizing little crystals both in the quartz grains and in the cement between them are believed to be zircons. Finally, there are in some of the sections bright yellow irregular fragments the nature of which was not determined.

The only mineral requiring a detailed description for the purpose in hand, which is to find out, if possible, something in regard to the origin of the material from which the sandstones were formed, is the quartz.

The quartz in thin sections occurs in large and small grains. An apparently continuous large grain breaks out often under crossed nicols into an aggregate of small grains showing different orientation. Some of the large grains are cracked and filled in along the cracks, sometimes with calcite and sometimes with hydroxide of iron. Most of the quartz grains are quite full of inclusions. In some cases, a grain is grown through in every direction with needles, which are colorless, brown, black, highly refracting, when light colored, and are probably rutile. In other instances, there are bright, highly refracting, colorless little crystals that closely resemble and are believed to be zircons. Of all the inclusions, by far the most abundant are irregular-shaped, round, columnar, and dihexahedral bright little bodies, each usually surrounded by a dark rim. They occur single, or arranged in lines or groups. Some contain a single, movable bubble, and are liquid inclusions containing a gas bubble. The bubble in a few cases was found to move spontaneously, and to be constantly in motion. Others contain two or more bubbles, and are then believed to be glass inclusions. The dihexahedral bodies are negative quartz crystals, or holes having the shape of a quartz crystal.

---

[1] For this microscopic examination I am indebted to Dr. R. N. Brackett, of Clemson College, S. C.

As to the bearing of the facts on the question of the origin of the material from which these sandstones were formed, it may be said that besides quartz, two constituents occur, one, feldspar, common to all granites, and the other, biotite, belonging to certain classes of granites.

The quartz itself furnishes in its liquid and glass inclusions evidence of its deep-seated origin and of its formation from a molten magma under considerable pressure. This follows if the inclusions are, as is believed, glass inclusions, and if the liquid inclusions contain gas bubbles, such as carbon dioxide or some gas requiring pressure for liquefaction. Besides, all the inclusions found in the quartz grains are quite characteristic of and common in quartz grains found in granites and other rocks formed at great depths and under considerable pressure. It is true that both rutile and zircons are found in metamorphic schists, the former being more characteristic of schists and other metamorphic rocks than of rocks which are believed to have solidified from a molten magma. But the glass inclusions certainly furnish evidence of crystallization from a molten magma, and this, taken together with the liquid inclusions with a gas bubble, make it quite probable that the material for the formation of these sandstones is furnished by the disintegration of a granite or some rock formed under similar conditions.

The Origin of the Cementing Material.

I conceive of four possible sources of the lime carbonate with which the reef rocks are hardened, as follows: —

I. Dissolved by rain-water or spray from the beach sands themselves; that is, carried from the upper layers of the sand and deposited in the lower ones.

II. Deposited from the ocean water after having been derived (through the agency of carbon dioxide) from calcareous organic bodies in the sea.

III. Brought down from the land by streams.

IV. Dissolved from calcareous beach sands by fresh water streams entering behind them, and redeposited while passing seaward through these sands.

These sources will be considered in this order.

I. *Cement from the beach sands by rain-water or spray.* — The dissolving of lime carbonate by rain-water from the upper layers of calcareous sands, and its redeposition a little lower down, is a well-known phenomenon. Woodward mentions instances of blown sands having been hardened sufficiently by lime and iron to be used for building purposes.[1] This hardening is especially common in warm regions where abundant molluscan life and coral-forming animals, calcareous Algae, gorgonias, and the like so often contribute largely to the beach sands. Aeolian sandstones and the sands upon the shores of coral islands are often hardened by this process. But, so far as I can learn, and so far as my own observations go, the rocks whose cements are derived from their own beds in this fashion are so highly calcareous as to be practically pure limestones.

The rocks of Bermuda are spoken of by Vetch, Nelson, Rice, Agassiz, Thomson, and Heilprin as newly-formed limestones. Rice says, "The cement which converts all these fragmental deposits into solid rock is formed by the solution of the calcareous particles themselves,"[2] and he points out that these rocks are almost exclusively limestones derived from shells and other calcareous fragments.

Sir Wyville Thomson says the sand of which the white granular aeolian limestone is made "consists almost entirely of carbonate of lime. . . . When rain . . . falls upon the surface of the sand, it takes up a little lime in the form of bicarbonate, and then, as it sinks in, it loses the carbonic acid and itself evaporates, and it leaves the previously dissolved carbonate of lime as a thin layer of cement, coating and uniting together the grains of sand. . . . The extreme result is a compact, marble-like limestone."[3]

---

[1] H. B. Woodward, The geology of England and Wales, ed. 2, p. 546–547. London, 1887.

The same author cites several instances of the induration of marine deposits (p. 550–551).

[2] Wm. North Rice, The geology of Bermuda. Bull. 25, U. S. Nat. Mus., p. 10. Washington, 1884.

[3] C. Wyville Thomson, The Atlantic. Vol. I., p. 291–295. New York, 1878.

I do not find that Mr. Alexander Agassiz mentions the precise process by which the aeolian deposits were hardened, but it seems quite evident throughout his paper on the Bermudas[1] that he thinks the sands are all calcareous, of organic origin, and cemented on land by rain-water, after having been blown up from the shores. Verrill lays stress upon "the secondary infiltration . . . of calcium bicarbonate and the deposition of calcite," and he notes that "this zone of calcification" would always be higher than high tide-level.[2]

Jukes mentions the cementation of such calcareous sands by rain-water[3] in Australia, and Dana speaks of similar phenomena on the Hawaiian Islands.[4]

"At King George's Sound in Australia . . . the upper layers . . . have been hardened by the action of rain on the friable calcareous matter, and the whole mass has originated in the decay of minutely comminuted sea shells and corals."[5]

Many cases have been noted of the consolidation of beach sands by ocean spray blowing over them. On the island of St. Croix mention is made of shells and other substances, including iron utensils on shore, having spray charged with calcareous matter dashed over them. "These generally unite and harden, especially near the surface, and form into a tolerably compact mass."[6] Evidently the hard rocks are in process of formation.

The only analyses seen of the beach-hardened calcareous sandstones are those given by the writer. These are of the aeolian sandstones of the islands of Fernando de Noronha. They show those rocks to contain, in one case, 98 per cent of lime carbonate and less than one per cent of silica; in another instance, the analysis showed 97 per cent of lime carbonate and two per cent of silica.[1]

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[1] A visit to the Bermudas in March, 1894. Bull. Mus. Comp. Zoöl., XXVI., No. 2. Cambridge, 1895.

[2] A. E. Verrill, Notes on the geology of Bermuda. Amer. Journ. Sci., 4th Ser., IX., May, 1900, p. 321.

Captain Vetch, in Trans. Geol. Soc., 2d Ser., I., p. 172. London, 1824.

On the calcareous sandstones of the Bermudas, see also Richard J. Nelson, Trans. Geol. Soc. London, 1840, V., p. 103–123.

A. Heilprin, The Bermuda Islands, p. 30–32. Philadelphia, 1889.

J. Walter Fewkes, On the origin of the present form of the Bermudas. Proc. Bost. Soc. Nat. Hist., 1888, XXIII., p. 518–522.

[3] J. Beete Jukes, Narrative of the surveying voyage of the H. M. S. "Fly." Vol. I., p. 9; 128; 339. London, 1847.

[4] J. D. Dana, Corals and coral islands, ed. 3, p. 155. New York [1890].

[5] Darwin, Geological Observations, ed. 2, p. 248. London, 1876.

[6] S. Hovey, The Geology of St. Croix. Amer. Journ. Sci., XXXV., p. 72. New Haven, 1839.

The analysis of the Brazilian reef rock, on the other hand, shows that it is made up of about two parts of silica to one of lime carbonate, including both cementing material and shell fragments.

It does not seem improbable, judging solely from the amount of lime carbonate in the rock, that the cementing materials may have come from these same sands, having been dissolved from one part of the beds and deposited in another.

II. *Lime carbonate from the ocean.* — Hartt long ago suggested that the lime carbonate by which the reef rocks are hardened was deposited from sea-water.[2] Such an explanation, however, can be looked upon as satisfactory only when it is accompanied by some explanation of the source of the lime, and the method and process of its deposition. It may well be objected to this theory that the beach sands in many parts of the world are quite as calcareous as those of northeastern Brazil, that the surf breaks upon these sands in the same way as it does upon the Brazilian beaches, and yet they are not hardened by the deposition of lime carbonate. Evidently a satisfactory explanation should deal with this part of the problem.

The theory of the process of hardening by lime carbonate from the ocean water is briefly: that the carbon dioxide escapes where the surf breaks upon the seashore, just as it escapes from streams at cataracts, or wherever a disturbance throws the lime-charged waters into spray, or in any way lets the air at the water.[3] Such surf should precipitate both lime carbonate and iron, the latter being in solution as ferric carbonate, and being precipitated as ferric oxide. The lime is thought to be held in solution as a bicarbonate, and to be deposited as a lime carbonate.

What is the source of the carbonic acid necessary to form the lime carbonate with which the Brazilian reef sands are hardened?

And why is this process of lithification not a universal one?

I conceive of two methods by which the carbon dioxide might come from the ocean. 1. By submarine discharge of CO_2 of volcanic origin. 2. CO_2 derived from the sea-water itself.

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[1] Amer. Journ. Sci., April, 1890; XXXIX., p. 249–256.

[2] Ch. Fred. Hartt, Geology and physical geography of Brazil, p. 343. Boston, 1870. Amer. Nat., June, 1879, XIII., p. 347–358.

[3] George Murray, in his Introduction to the study of seaweeds, p. 8, points out that air introduced into or passed through sea-water carries off carbon dioxide.

Carbon dioxide of submarine volcanic origin. — The carbon dioxide ordinarily found in the sea is not free but combined in carbonates and bicarbonates.

In the case of carbon dioxide of volcanic origin discharged in the sea, it might remain chemically dissolved in the water, $(CH_2O + CO_2) = (H_2\ CO_3)$, but as soon as it came in contact with calcium or magnesium, the carbon dioxide would dissolve the lime carbonate, whether in the calcareous shells of living mollusks, corals, and crustaceans, or in the broken fragments of dead ones on or near the shores. A bicarbonate would be formed and held in solution until precipitated out or otherwise removed as a carbonate.

It is but natural that one should object at the outset to a theory that seems to be so far-fetched — to a source so out of the ordinary course of events as does the one here suggested. But the source is really not so extraordinary as it at first appears.

The most valuable observations upon the gases emitted by volcanic eruptions with which I am acquainted is that of Fouqué upon "Santorin et ses eruptions," published at Paris in 1879. In his study of that interesting locality M. Fouqué found that —

a. The carbonic acid discharges became more and more marked after the seasons of greatest volcanic activity.

b. That the compositions and temperatures of gases were but little affected by passing through waters (p. 229).

c. That variation of the gases is the same for subaqueous as for subaerial volcanoes (p. viii).

The pouring out of volcanic eruptions beneath the ocean is not an uncommon occurrence. Indeed, Sir Archibald Geikie lately remarked that "With regard to the supposed impossibility of lavas having flowed under the sea, he could only observe that no facts in the geological history of Britain were more abundantly proved than that from the earliest Palaeozoic periods the vast majority of the volcanic eruptions in our region have been submarine."[1] . . . Sometimes the products of these eruptions rise above the water's surface, forming islands, as in the cases of Graham's Island in the Mediterranean Sea,[2] islands off the west coast of Iceland, and Bogoslof off the island of Unalaska.

The island of Bogoslof, as it is now called, was first described by Langsdorff. He says that in 1795 the people of Unalaska observed the appearance of a fog in the vicinity of the rock, and upon visiting it they found "the sea all about the rock boiled, and that the supposed fog was the smoke or vapour that rose from it." After about five years the fog cleared away, and fire and smoke were seen issuing from a peak upon the island. At the time of Langsdorff's visit in 1806, the lava was still running from the island into the sea, and the sides of the peak were hot.[1] These and other cases of submarine eruptions are cited by Scrope.[2] Mr. W. G. Foster of Zante, Greece, has also called attention to evidences of submarine eruptions afforded by the burning of submarine cables.[3] These eruptions did not reach the surface of the seas. Dr. Sambon tells of the breaking of cables by submarine eruptions on several different occasions, of the boiling of the sea, and of the escape of gases[4] through the sea-water.

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[1] Quar. Journ. Geol. Soc., May, 1898, LIV., p. 233.

[2] H. J. Johnston-Lavis. For bibliography of this island, see The south Italian volcanoes, p. 105–107. Naples, 1891.

Sainte-Claire Deville[5] found carbonic acid emerging lower down on Vesuvius than ammoniacal gases, toward the end of an active period of eruption, and always cold. He considers these discharges as an effect and as the last act of eruptions.

Fouqué's later and more extended studies "confirm the law of the variation of volcanic gases first established by Ch. Sainte-Claire Deville."[6] He also found that the law in regard to the order of discharge of the various gases is the same for submarine as for subaerial volcanoes.[7] By direct observation he ascertained that from 4 to 88 per cent of the gases obtained from the fumaroles of Santorin were carbonic acid.[8] This gas escapes even when volcanic activity is dormant, and in some cases accumulates in considerable quantities in depressions such as the Valley of Death in Java, where animals are often suffocated. "In Java there is a crater, called the 'Guevo Upas,' or 'Poison Valley,' half a mile in circumference, always so full of carbonic acid gas that every living thing that passes its limits is suffocated, and the ground is strewed with the carcases of wild animals, birds, and even of men that have met their fate there. . . . Exhalations of carbonic acid gas occur abundantly in many other districts which were the former seats of volcanic action." . . .[1]

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[1] G. H. von Langsdorff. Voyages and travels in various parts of the world, Part II., p. 242–245. London, 1814.

W. H. Dall. A new volcanic island in Alaska. Science, Jan. 25, 1884, III., p. 89–93.

I. C. Russell. Volcanoes of North America, p. 276–281. New York, 1897.

Kotzebue's Voyage of discovery, Vol. III., p. 287. London, 1821.

[2] G. Poulett Scrope. Volcanoes, ed. 2, p. 236–238, London, 1862.

[3] Trans. Seismological Society of Japan, Vol. XV., p. 73. Yokohama, 1890.

[4] L. Sambon. Notes on the Eolian Islands and on pumice stone. The South Italian volcanoes. Edited by H. J. Johnston-Lavis. p. 64–65. Naples, 1891.

[5] Bull. Soc. Géol. de France, XIII. ser. 2, p. 640. Paris, 1855–6.

[6] F. Fouqué. Santorin et ses eruptions, p. 232. Paris, 1879.

[7] *Op. cit.*, p. viii.

[8] *Op. cit.*, p. 225.

In Death Gulch, Yellowstone National Park, a volcanic region, it rises from the waters to such an extent as to suffocate wild animals, — even grizzly bears.[2]

Fouqué shows that within certain limits carbonic acid is emitted about volcanoes in larger proportions as one leaves the more active vents, and Sainte-Claire Deville shows it to be a prominent gas of fumaroles.[3] Sir William Hamilton speaks of noxious gases about Vesuvius killing birds and other animals, and even persons.[4] Some of these gases seem to act like carbon dioxide.

Daubeny refers to these gases, and says that they are supposed to consist chiefly of carbonic acid gas.[5] In another place he states that "carbonic acid is a common product of volcanoes nearly extinct; it is emitted, as we have seen, very abundantly from fissures in the neighborhood of Naples, as well as near Rome, in the Vivarais, in the Eyfel. . . . It is supposed that the Mofettes, which often succeed an eruption of Vesuvius, consist of this gas; but it is remarkable that during a state of vigorous action this volcano does not appear to emit it." [6]

Dr. Johnston-Lavis tells of the escape of carbon dioxide from springs of Sujo and from other openings in the vicinity of Roccamofina (between Rome and Naples) in sufficient quantities to suffocate human beings.[7]

Now we have satisfactory evidence in the Fernando de Noronha group of islands of volcanic activities off the northeast coast of Brazil. This group lies two hundred miles northeast of Cape St. Roque, and, with the exception of certain small areas of æolian sandstones, is made up entirely of eruptive rocks.[8]

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[1] G. Poulett Scrope. Volcanoes; the character of their phenomena, etc., ed. 2, p. 151–152. London, 1862.

[2] T. A. Jagger, Jr. Death Gulch, a natural bear-trap. Pop. Sci. Monthly, Feb, 1899.

Ward in *Science*, March 24, 1899, p. 459.

[3] Russell's Volcanoes, p. 52.

[4] Wm. Hamilton, Observations on Vesuvius, Mount Etna, and other volcanoes, p. 164–167. London, 1774.

[5] Charles Daubeny. A description of active and extinct volcanoes, p. 161. London, 1826.

[6] *Op. cit.*, p. 375.

[7] H. J. Johnston-Lavis. The south Italian volcanoes, p. 77–79, and plate xvi. Naples, 1891.

[8] J. C. Branner. The geology of Fernando de Noronha. Amer. Journ. Sci., 1889, XXXVII., p. 145–161.

We have no means of determining the age of the rocks of these islands, but the freshness of the lavas and the rapidity with which the shores are being eroded by wave action lead us to infer that they are new.[1]

The position of these eruptive islands affords a basis for the theory that either at the time of the extrusion of the rocks that form the group, or at some subsequent eruption, large quantities of carbon dioxide may have escaped into the sea. The South Atlantic current at this latitude flows westward, but during eight months of the year (October to May, inclusive) the northeast trade winds shift it somewhat toward the south, so that during those months the oceanic currents that pass Fernando flow toward Cape St. Roque, and thence pass southward along the east coast of Brazil, past Rio Grande do Norte, Pernambuco, Rio Formoso, Bahia, etc. These currents would have thrown the carbon dioxide, had they contained it, against the shores along the northeast coast of Brazil from Cape St. Roque southward.

But if submarine discharges of carbon dioxide have taken place, and if beach sands have been hardened as here suggested, we may reasonably expect to find beach sands similarly consolidated in other parts of the world. There are indeed many cases known of the hardening of recent beach sands. In only two instances, however, do they appear to have been hardened by carbon dioxide escaping from submarine vents: these are in the Straits of Messina between Sicily and Italy, and on the shores of the Red Sea.[2] In both of these cases the consolidation has taken place in the vicinity of volcanic activity.

We seem warranted in the conclusions that carbon dioxide of volcanic origin is discharged beneath the sea; that it is competent to cause the hardening of beach sands; and that the existence of a volcanic island off the northeast coast of Brazil makes it possible that such discharges may have taken place there. But inasmuch as the lithification of the coast sands of the region is in various stages of development, and as there are in many places several reefs overlapping each other, it seems probable that the process on the Brazilian coast is an approximately continuous one to which this method of derivation is hardly applicable.

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[1] Northwest of Fernando de Noronha and eighty miles away is another small island known as the Rocas. This island is about two miles long (east-west) by one and three-fourths miles wide, and was until lately uninhabited. I have never visited the place, but from information kindly furnished me by Commandante Huet Bacellar, of the Brazilian navy, who has visited the place, I conclude that the rocks there are corals. But whether the corals have igneous rocks beneath them, I have been unable to learn. Except some dunes on the southwest corner, it is all covered by water at high tide. On the Rocas, see p. 226–227 of this report.

[2] Hawkshaw, Quar. Journ. Geol. Soc., 1879, XXXV., p. 242.

Suess says history mentions many eruptions on the Red Sea. *Face de la Terre*, p. 478, note.

Carbon dioxide from sea-water, but not of eruptive origin. — Analyses of sea-water show that it contains carbon dioxide in considerable but varying quantities. It is most abundant in the cold waters of polar regions and of the deepest oceans.

Dittmar says the atmosphere and the decay of organisms supply this carbon dioxide, but he seems to think that most of it issues, like submarine springs, beneath the ocean waters.[1]

Knudsen thinks that "predominance of animal or vegetable life in any part of the sea causes the variations in the amount of contained oxygen or carbonic acid."[2]

In studying this matter we should not lose sight of the fact that marine animals having lime carbonate skeletons do not derive that lime carbonate directly from the water, but they must get it through the agency or interposition of the plants they use for food; that is, the plants take it from the water and deliver it to the animals. We need not especially concern ourselves, however, with the source of supply; for present purposes the fact of prime importance is this difference in carbon dioxide contents between the polar and tropical sea-waters, and the general tendency of the carbonates to accumulate at the equator.[3]

Whatever may be its cause, there is then a general tendency for carbon dioxide to be taken up about the poles and liberated in the tropics. Dr. John Murray pointed out in 1889 how the organic matter in the ocean is attacked and dissolved by sea-water. "As soon as life loses its hold on the coral structures, and wherever these dead carbonate of lime remains are unprotected . . . they are silently, surely, and steadily removed in solution."[4] The methods by which the sea-water gets access to the calcareous particles can be seen along coral reefs and in similar shallow seas during a gale. The waters are affected to a greater depth than usual, and the softer debris over the bottom is stirred up and mixed with the water, giving it a milky appearance. Under such circumstances, the calcareous particles are exposed to the water through its entire depth.

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[1] Report on the scientific results of the exploring voyage of H. M. S. "Challenger." Physics and Chemistry, I., p. 213. London, 1884.

[2] Nature, June 30, 1898, LVIII., p. 201.

[3] On the distribution of diatoms in polar seas, see An introduction to the study of seaweeds, by George Murray, p. 19, 197. London, 1895.

[4] Nature, 1889, XXXIX., p. 424.

That the deep cold ocean waters dissolve lime deposits readily is distinctly shown by the fact that deep dredging brings up little or nothing in the way of calcareous shells and bones, and of sharks' teeth only the hard dentine, and only the hard earbones of whales, while the larger bones have been dissolved. The chemical process involved seems to be the formation of bicarbonates, and later the deposition of carbonates upon the liberation of carbon dioxide.

In ordinary chemical laboratory work it is the practice to precipitate carbonates from solutions by raising their temperatures. In such cases it is understood that a part of the carbon dioxide is driven off by the increase of temperature, while the lime or magnesia is precipitated as a carbonate. This increase of temperature is not necessarily great, — not near the boiling point. Similar increase of the temperature of ocean waters is produced by the waters breaking in surf or rolling upon the warm sandy beaches of the tropics. The whole process results, therefore, in a general tendency for the carbonates to accumulate in the tropics. But this accumulation must take place at or near the surface of the waters, for the coldness and the pressure at great depths would keep the carbonic acid free.[1] Only when the pressure is relieved, and the temperature raised near the surface, is there any opportunity for combination and for the formation of carbonates.

Waters carried from a cold sea into a warm one, or from the cold depths to the surface and warmed suddenly, would yield up their carbonic acid contents. The form of the continental shoulder of northeast Brazil, and the on-shore direction of the currents, favor this process. The accompanying map (Plate 1) gives in contours the relief of the sea floor along the Brazilian coast out to the one-thousand-fathom line. This map shows that the continental margin lies only from twenty-five to thirty-five miles off the shore. When the oceanic currents strike this steep submarine escarpment, the colder waters are swept up from the depths, quickly warmed at the surface, and made ready to yield up their carbonic acid contents. Observations upon the waters themselves bear out this view.

Waters of the Atlantic Ocean between Fernando de Noronha and Pernambuco vary in temperature from 30° at five hundred fathoms to 78° at the surface.[2] In general the surface layer of warm water is thicker on the east shore of a continent than on the west shore,[1] and as Murray points out, this favors the growth of corals along the eastern shores of the continents. It must also favor the yielding up of carbon dioxide. The conclusion seems warranted from these facts that the warming of the sea-water of the South Atlantic equatorial current that sets against the northeast coast of Brazil is capable of supplying all the carbon dioxide necessary for the hardening of the stone reefs.

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[1] The Prince of Monaco says Dr. Jules Richard found that gases "are not dissolved in the depths at any other pressure than they are at the surface." Nature, June 30, 1898, LVIII., p. 201.

[2] Challenger Reports. Phys. and Chem. I. pt. I., Plate 78. London, 1884.

Is the process universal? — But if the hardening of these beaches is produced by the sea-water alone, why is it that the process is not a universal one, at least in the tropics?

From what has gone before, it might appear that it was simply a matter of carbon dioxide, either of volcanic origin or derived from cold sea-waters by warming them, in which case we might expect such beaches in almost any part of the world.

Now the relations of ocean currents and temperatures to carbonic acid are not new, but must have existed for a long time. If the sands of tropical shores have been consolidated by the aid of carbonic acid brought in by ocean currents, this process of consolidation must have been going on ever since the present currents were established, and it must be going on to-day. Confining ourselves to the Brazilian coast, we should expect to find, therefore, not a single or double line of stone reefs, but a continuous series of hardened beaches overlapping each other, wherever the coast line has been extended seaward by accretion, or exposed wherever the ocean tends to encroach upon the land. As a matter of fact, this is not the case in Brazil.

Dr. Dall says[2] that in Florida "Coquina rock, frequently composed more of sand grains than of shell, . . . is doubtless being formed at many points along the Gulf shore, though in small quantities at each place, and not at all in the lagoons and harbors." He mentions a recent rock that contains land and marine shells, in some places soft and in other places (without fossils) ringing under the hammer. What cements this rock he does not state. Another is said to be hardened by iron brought out in spring waters; still another is hardened by lime coating the sand grains. (*Loc. cit.*, p. 164.)

In order to ascertain whether recently consolidated beaches were known about the British Isles, I have corresponded with Mr. W. Whitaker, lately President of the Geological Society of London, and some time member of the committee of the British Association, "appointed for the purpose of inquiring into the rate of erosion of the sea-coasts of England and Wales."[1] So far as his own observations go, Mr. Whitaker tells me that he does not recall a single case of the hardening of beach sands. He gives me, however, the following interesting unpublished note made by Bauerman, in connection with one of Mr. Whitaker's papers on the Alderley Edge Copper-works, written in 1861 or 1862: —

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[1] Murray and Irvine. Nature. June 12, 1890. XLII., p. 163.

[2] W. H. Dall, Notes on the geology of Florida. Amer. Journ. Sci., 3d ser., XXXIV., p. 163.

> "A curious deposit of a similar character has been noted in Cornwall, at the Perran Mine near St. Agnes. The slow oxidation of small quantities of copper-pyrites in the wash heaps of the old works, which rest upon blown sand, produced soluble copper salts which were infiltrated by the rain into the sand below, producing irregular concretionary masses cemented together by green carbonate of copper. Many of the larger modules contained quartz pebbles and snail shells. These sands were worked as copper-ores in the year 1853."

There must be more or less of the hardening of beach sands, however, on almost all shores during the summer months where the shallow waters are warmed by the sun. But unless this hardening passes a certain amount, it can never produce perceptible effects, because storm-waves during the rest of the year break up this incipient consolidation. In the tropics this sort of deposits is more common.

"At many points on a reef where evaporation takes place, there is a deposition of amorphous carbonate of lime cementing the whole reef materials into a compact conglomerate-like rock."[2] These consolidated beaches, however, appear to be local rather than widespread, even in the tropics.[3]

If the preceding facts were the only ones concerned in the inorganic deposition of lime carbonate, we might reasonably expect to find the beaches of all tropical seas solidified by lime deposits. It is unnecessary to say that such is not the case. So far as mere temperature goes, the surface waters along the northeast coast of Brazil are probably neither warmer nor colder than those along the shores in many other places within the tropics. And yet the northeast coast of Brazil is almost the only one along which the beaches have been extensively solidified.

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[1] Report of the British Assoc. Adv. Sci. for 1885, p. 402–442.

W. Whitaker, Chronological list of works on the coast changes and shore deposits of England and Wales. Rept. Brit. Assoc., 1885, p. 442–465.

W. Whitaker, Second chronological list, etc. Rept. Brit. Assoc., 1895, p. 388–402.

[2] Murray. Nature. Feb., 1889, XXXIX., p. 427.

[3] For other examples of the consolidation of beach sand by sea-water, see "A voyage of discovery into the South Sea," etc., by Otto von Kotzebue. III., p. 332. London, 1821.

James D. Dana, Corals and coral islands, 152. New York, 1890. Amer. Journ. Sci., 1885, CXXX., p. 103.

James D. Dana, Points in the geological history of the islands Maui, and Oahu. Amer. Journ. Sci., 3d ser., XXXVII. 1889, p. 89.

A. Agassiz, A visit to the Great Barrier Reef of Australia. Bull. Mus. Comp. Zoöl., XXVII., No. 4, p. 108, and Plate IV. Cambridge, 1898.

In view of the exceptional character and extent of the stone reefs of Brazil, it must be admitted that the theory of the deposition in them of lime carbonate, due solely to the increase of the temperature of the water, is not satisfactory.

III. *Lime carbonate from the land.* — Waters flowing from a land surface of limestone would necessarily be charged with lime. If such streams entered the sea without other dilution, there would be a tendency for them to deposit their lime contents immediately upon entering the sea. This precipitation is due to the saturated condition of the two waters. The Rhone, emptying its strong lime waters into the Mediterranean Sea, deposits lime with its silts, and the beaches about its mouth are in many places consolidated. Lyell remarks, in speaking of this matter: "If the number of mineral springs charged with carbonate of lime which fall into the Rhone and its feeders in different parts of France be considered, we shall feel no surprise at the lapidification of the newly deposited sediment in this delta."[1]

The rocks of western Palestine and of southern Asia Minor are made up almost entirely of limestone, so that the streams flowing from that land surface enter the already dense waters of the Mediterranean Sea heavily charged with lime, and the precipitation of that lime on the shores has made the reefs and consolidated beaches described by Beaufort,[2] Botta,[3] Lartet,[4] and Hull.[5]

Inasmuch as the stone reefs of the Levant seem to be about the only extensive ones in the world comparable with those of northeast Brazil, it seems best to give here some account of them and of the conditions under which they appear to have been formed, in the hope of getting light upon the Brazilian stone reefs.

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[1] Charles Lyell, Principles of geology, ed. 11, I., p. 426. New York, 1889.

[2] F. Beaufort. Karamania, p. 10, 13, 174, 178, 207, 211, 212, 253, 289. On lime in the streams, p. 130, 135-136, 141, 191, ed. 2. London, 1818.

[3] Observations sur le Liban, etc. Mem. Soc. Géol., France, ed. 1, p. 135-160.

[4] L. Lartet. Exploration géologique de la Mer Morte. Paris, 1877.

[5] E. Hull. The survey of Western Palestine. Physical geology and geography. London, 1886.

The consolidated beaches of the Levant. — The earliest descriptions of the reefs of Asia Minor known to the writer are those given by Francis Beaufort.[1] He is quoted here at some length (p. 182–186) : —

> "The shore bounding this plain was once a gravel beach; but from the upper part of the slope to some distance into the sea, it is now a solid crust of pudding stone, from one to two feet in thickness. This petrified beach is not peculiar to the plain of Selinty ; many instances of it on a smaller scale had been already observed on the coasts of Asia Minor, and a few on those of Greece ; and I have been informed that an example of it occurs also in Sicily. Being generally covered with loose sand and pebbles, it presents to the eye no extraordinary appearance. . . . The specimens that I have examined, taken from various places, differ but little from each other; gravel predominates in some, coarse sand in others, or they lie in alternate layers of each. . . . The cement or paste by which they are united is likewise calcareous ; and so tenacious that a blow sufficient to break the mass, more frequently fractures even the quartz pebbles than dislodges them from the bed.
>
> "Close to the westward of Side we had found some ledges of rock, partly above and partly under water, which appear to have been produced in a similar manner : they contain a large proportion of broken tiles, both red and yellow, of shells, bits of wood, and of such rubbish as might be expected in the vicinity of a town. . . . At Phaselis also we found a patch of petrified beach ; and again at a few miles to the eastward of Alaya. . . . It is needless to enumerate here all the places where it may be found on this coast."

On page 249 this writer gives a small map of Pompeiopolis in which the ancient port is shown to have been filled up with blown sands, and these sands have become solidified on the beach within the port. (See also p. 260.)

The last case shows that the hardening of the beach has taken place within historic times.

Beaufort's description of these beaches refers to the southern coast of Asia Minor from the Island of Rhodes eastward.

Along the coast of Palestine these same phenomena are reported by Botta.[2] His description of the reefs is given as a postscript to the article proper, as follows : —

> "P. S. Since this memoir was written I have gone to see a fact first pointed out to me by Dr. Hedenborg. Along the whole coast of Beirout or El Arich to Tripoli is found a kind of conglomerate or argillaceous sandstone

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[1] Francis Beaufort. Karamania, or a brief description of the south coast of Asia Minor, ed. 2. London, 1818.

[2] P. E. Botta Fils. Observations sur le Liban et L'Antiliban. Mém. Soc. Géol. de France, Tome I., p. 135–160. Paris, 1833.

of varying coarseness which, in his opinion as well as my own, is a late formation. They generally occur as breakers (ecueils) along sandy coasts always below high tide and without any connection with the limestone of the coast. My specimens were collected in a small sandy bay between Beirout and Antours, near a café called Donkhane el Doubbait. The conglomerates there are in small irregular beds, always horizontal, washed by the sea, in the midst of sands exactly like the rocks. This deposit gradually obstructs the ports of the coast, and though there are no corals or madrepores on this coast, it forms some small ports similar to those found among the coral banks and islands of the South Sea ; such are those at Sour (Tyre) and at Jaffa. When they come from the water they are not very solid, but they become very hard when exposed to the air, so that a great many houses along the coast are built of it. As at Saide, Sour (Tyre), Jaffa el Arich, etc., on the coast of Djibail, I have seen some yellowish varieties that looked to me quite similar to the conglomerates that I have seen at Palermo and at Messina, and which are generally known to be still in process of formation. I have not found any containing whole shells, and this is in keeping with their variety on these shores, but one of the specimens has fragments still quite fresh. Among the grains some are siliceous, others calcareous. The cement that unites them seems to be of the latter kind. In size, they vary from that of an apple to that of the finest sand. In considering the position and nature of these conglomerates, and in comparing them with what I have seen elsewhere, I am convinced of their recent formation. At the same time I am led to believe that it is alternative, that is to say, that it does not occur constantly, for they are generally arranged in beds and these are of different hardnesses like those of the trunk of a tree."

Still later Lartet[1] mentions these Palestine reefs: —

"On this coast of Phonicia and parallel with the shore are lines of rocks forming breakwaters in some places and in others very dangerous rocks. It is doubtless on account of an upward movement that these hardened sand banks rise to and appear above the water.

"In going ashore at Jaffa we were obliged to go through a dangerous passage in the breakers that rise a little above the sea. . . .

"These sandstones of recent date form beds that follow the coast regularly at a certain distance from the shore and generally rise just to the surface of the water. . . . The calcareous sandstones usually make along the sandy shores (lines of) rocks below high-water mark that are composed of the same materials as the beach sand and sometimes contain some horizontal and irregular beds of conglomerate.

"According to Botta, these deposits gradually obstruct the ports of the coast, and though there are no corals or madrepores there, they form small ports like those among the coral banks and islands of the South Sea. As soon as they are exposed to the air, the rock hardens and is used as we have seen as a building stone at Sidon, Tyre, Jaffa, and Asrisch. The shores of the Red Sea are producing analogous marine formation, and the ports are being partly obstructed by the development and slow elevation of the coral reefs."

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[1] L. Lartet. Exploration géologique de la Mer Morte de la Palestine, p. 199. Paris, 1887.

What seems to be a continuation of the same reef at Jaffa is thus described by Hull:[1] —

> "A natural breakwater of calcareous sandstone projects outwards into the Mediterranean from the ancient walls at the south end of the town (of Jaffa). Outside this all large ships are obliged to cast anchor, and passengers as well as cargoes have to be received and discharged by means of boats, which frequently have to breast a heavy surf. The rock is seen under the lens to be composed of comminuted shells, pieces of coral, and other marine forms; and it appeared to me to be of recent formation, raised into the air when the whole sea-bed was being elevated. A similar formation of shelly limestone appears to be in process of consolidation along the shore further towards the north, where it is quarried just under the sands at the margin of low water. The shells of which it is formed are those which strew the shore in immense numbers, chiefly those of *Pectunculus glycineris.*"

The preceding descriptions of the reefs of the Levant show that they bear some resemblance to the stone reefs of Brazil. They follow the coast line closely, and have been produced by the recent hardening of beach sands by the deposition of lime carbonate.

Mention has been made of consolidated beaches upon the shores of the Red Sea. Hawkshaw barely speaks of having seen such beaches.[2] Dr. Buist speaks of elevated beaches on the shores of the Red Sea,[3] and the rocks of the region are said to be "nummulite limestone." He observes, however, that there is not a stream along its shores (p. 280), — a matter of importance in connection with the present discussion.

In his paper upon "Pleistocene shells from the raised beach deposits of the Red Sea," Mr. R. Bullen Newton[4] mentions many raised beaches, some of them having an elevation of as much as 560 feet above sea-level, but his paper is a palaeontologic one, and nothing is said of the condition of the materials forming these old beaches.

In a later article by Dr. Hume,[5] mention is made of elevated beaches over twenty metres high on the eastern side of the Red Sea. In Wadi Hashubi he found the sand grains cemented by carbonate of lime, and at the mouth of Wadi Nasb, are gravels cemented by calcite. Dr. Raisin says there are low raised beaches on Perim Island in the Straits of Bab-el-Mandeb.[1]

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[1] Edward Hull. Mount Seir, Sinai and Western Palestine, p. 148. London, 1889.

[2] Quar. Journ. Geol. Soc., 1879, XXXV., p. 242.

[3] Buist. On the physical geography of the Red Sea. Journ. Roy. Geog. Soc., XXIV., p. 227–238. London, 1854.

[4] Geol. Mag., Nov. and Dec., 1900.

[5] W. F. Hume. Geology of Eastern Sinai. Geol. Mag., 1901, VIII., p. 200–204.

Without more definite information it is impossible to say whether or not the beach deposits of the Red Sea are similar in nature and origin to those of the coast of Brazil. Unfortunately a letter of inquiry, regarding this matter, to the geologist in charge of the Egyptian survey received no reply.

Leaving the Red Sea out of account, there still remains the question why this hardening is not more general: why is it apparently confined to the beaches of the Mediterranean Sea and of northeast Brazil?

RELATIONS OF DENSITY TO DEPOSITION.

The salt water of the sea of a necessity cannot hold in solution as much lime carbonate as can fresh water. This is due to the fact that sea-water already holds so much mineral matter, most of which is more soluble than the carbonate of line. It follows for the same reason that the denser the sea-water the less carbonate of lime it will be able to hold, or the more ready it will be to give up and deposit any that it may have or receive in solution. We should, therefore, expect that waters holding much carbonate of lime in solution, on flowing into the sea, would deposit it more promptly in denser than in less dense sea-water.

Jukes-Browne points out "that where a body of fresh water, containing much carbonate of lime in solution, enters the sea, and remains exposed to surface evaporation, a precipitation of carbonate of lime will take place."[2]

There is a perceptible and probably constant variation in the density of sea-water in spite of its movements and its commingling, and this variation must influence the precipitation of lime in the beach deposits. Furthermore, any increase of the density of the sea-water would hasten the precipitation of the carbonates, and as it is precisely in the tropics and in arid regions that the sea-water is densest, it is there that there is the greatest tendency of the carbonates to be deposited upon the beaches.

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[1] Geol. Mag., March, 1902, IX., p. 132.

[2] A. J. Jukes-Browne. The student's handbook of physical geology, p. 213. London, 1884.

The accompanying map taken from the chart of the "Challenger" Reports, Physics and Chemistry, Vol. I., shows the areas of densest sea-waters over the globe. The variation in density must be due to the different rates of evaporation. The almost closed basins of the Mediterranean and Red Seas are in warm, arid, or partially arid regions, where evaporation goes on very rapidly. Some of the streams entering these basins are heavily charged with lime, so much so that fresh-water tufa deposits are forming at many places on a large scale. On entering the sea the dense salt waters tend to hasten the deposition of the lime, and this takes place most readily upon the beaches where evaporation is most rapid.

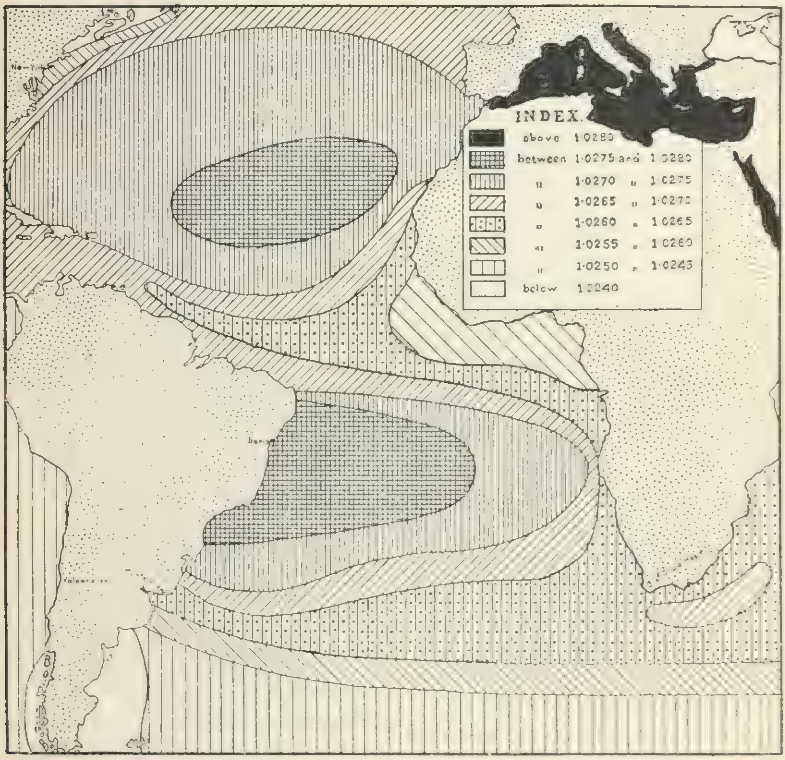
INDEX.
above 1·0280
between 1·0275 and 1·0280
" 1·0270 " 1·0275
" 1·0265 " 1·0270
" 1·0260 " 1·0265
" 1·0255 " 1·0260
" 1·0250 " 1·0245
below 1·0240

FIG. 95. Surface densities of sea waters ("Challenger").

The area of high sea-water density on the northeast coast of Brazil is probably to be attributed to rapid evaporation on the surface of the equatorial current that sets westward from the coast of Africa and crosses the whole width of the Atlantic under a tropical sun. By the time these waters reach the Brazilian coast, the density is greatly increased by evaporation.

If the process on the Brazilian coast were the same as that in the Mediterranean and Red Seas, the lime would be derived from the streams. This may or may not be the case. Unfortunately I have no analyses of the waters of the coast streams; but the geology of the region leads to the conclusion that some of the streams are heavily charged with lime, while others contain very little lime. The Cretaceous areas of Brazil are, or have been, largely limestone areas. From the Abrolhos to Ceará sedimentary rocks cover most of the coast.

In the introductory geological sketch of the coast it has been pointed out that where the sedimentary beds are unaltered, they contain considerable lime, even when they are not limestones. It has also been noted that the upper portions of these rocks along the whole length of the coast where the stone reefs occur, have been profoundly weathered and chemically altered. It seems probable, therefore, that during the process of the alteration of these upper beds large quantities of lime have been removed from the land and carried by the streams into the already heavily charged sea-water.[1] It is a striking and significant fact that the area of high density of the sea-water along the coast of Brazil corresponds closely with the distribution of the stone reefs.

Whether the cementing material was brought down from the land or was thrown upon the shores from the ocean, it seems that the unusual amount of hardening of beach sands along the northeast coast of Brazil is to be attributed indirectly to the density of the sea-waters in that region.

IV. *The seaward percolation of acid land-water.* — The density of the sea-water is, or may be, an element of controlling importance in the hardening of the reef rocks. It is also evident that this density is directly attributable to climatic conditions. But climatic conditions affect the land and its streams even more than they do the ocean.

No analyses of the waters of the streams of northeast Brazil being available, it cannot be said whether or not those streams are heavily charged with lime. But speaking from a general knowledge of those streams, I should say that outside of the State of Sergipe their waters are not so charged.

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[1] Murray shows that sea-water contains 2,000,000 tons of calcium to the cubic mile. Nature, February 28, 1889, XXXIX., p. 426.

It is not improbable, however, that the streams may be affected physically as well as chemically by climatic conditions.

Possible influence of climate. — In Chapter V., p. 143, it has been shown that only the strong streams are able to enter the ocean boldly; weaker ones are compelled to seek outlets behind barriers, such as spits, reefs, headlands, or other protection; while the still weaker ones are often closed altogether by the embankments of sand thrown across their mouths by the ocean.

In so far as precipitation is concerned, the climatic conditions of northeast Brazil are very variable. As a rule, even in years of abundant rains, the precipitation takes place in a few months, and the rest of the year is very dry.[1] For this reason the streams are spasmodic at best. But there are from time to time drouths that last for years. During these prolonged dry periods, all but the larger streams are completely dried up, or are converted into a string of stagnant pools. Streams in such a region must have their mouths closed during these long dry periods, even though they may be abundantly able to keep them open in seasons of heavy rains.

In all cases where the mouths of streams are closed, the waters are held in pools behind the embankments, and obliged to escape to the sea through the beach sands. Now the fresh-water pools thus shut out from the sea are the homes of enormous quantities of aquatic plants, and their margins are covered with a dense vegetation dropping its dead leaves and fruits in the water. This organic matter, upon decomposition, charges the water with organic acids. As the waters percolate seaward through the sands of the beach, especially during low tide, when the hydrostatic pressure of the water in the pools forces them forward, they attack the calcareous matter with which they first come in contact, and carry it along in solution until they encounter the sea-water. Here there would be a tendency for the less soluble lime to be precipitated, especially if there were a checking of the movement of the water.

Precipitation would thus take place along a beach-line, and would be confined to a rather narrow belt, for its width would be something less than that of the confining sand embankment, while its length would be determined by the coastwise length of the pools and of the restraining beaches.

The mouths of streams closed in this manner would in time be open again, and there would be established a long slender reef of hard sand rock with a break in it, through which the stream would discharge.

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[1] J. C. Branner. Decomposition of rocks in Brazil. Bull. Geol. Soc. Amer., 1896, VII., p. 309–312.

Changes in the in-shore ocean currents, such as are constantly occurring, would remove the consolidated sands from some parts of the reef and heap them in other places.

Some of the conditions here hypothecated exist at present on the southern coast of California. At and about Oceanside, San Diego County, the region has been depressed and silts have filled up the stream mouths and embayments. The streams are weak and spasmodic, and unable to keep their mouths open, even when opened by floods. The drainage waters collect in pools and marshes behind the long sand beaches, and escape by percolating through the beach sands. If these sands are calcareous, we may expect in time to see them hardened and turned into long lime-cemented sandstone reefs very like those of northeastern Brazil.

This hypothesis appears to fit most of the conditions observed along the stone reefs of Brazil: the streams and embayments across which the reefs lie are streams and areas of weak drainage; the reefs have the forms and structure of beaches; unconsolidated sands underlie the hard reef cap-rock.

At some places, however, the stone reefs rest against rocks through and from which these lithifying waters could not have passed. At Cape Santo Agostinho, for example, the northern end of the rock reef laps back against granites for a long way north of the embayment behind the Barra do Suápe. The percolation of acid waters from marshes and ponds landward of the present reef might have hardened shore sands in front of these marshes into a rock reef, but the sands that lay against the east face of the cape had no pools to the landward. If they were hardened by this process, the acid waters of the marshes must have saturated the sands for considerable distance up and down the coast, as well as in front of the marshes.

The hardening process is not a continuous one. — If the process by which the reef rocks are hardened were a continuous one, we might expect to find an overlapping series of sandstones filling the embayments. This overlapping series does not exist. There are sometimes two or three reefs, one behind the other, but even in these cases the reefs are separated from each other by softer layers of sands. The sections of the Pernambuco reef obtained by Sir John Hawkshaw also show that there are loose sands interbedded with the hard layers. The undermining of the reefs by the surf at many places along the coast shows that this alternation of hard and soft beds is a characteristic feature of the large stone reefs.

We are, therefore, obliged to conclude that the process of hardening is not perfectly continuous. This lack of continuity is not a time break, properly speaking, but simply a break due to local physical and chemical conditions.

That the beds of sand harden in some places and not in others is a well-known fact, though just why it happens so is not always clear. Nelson long ago called attention to the difference in the hardening of the calcareous sands of Bermuda,[1] and Dall notes the local hardening of the "coquina" in Florida.[2]

It seems probable at least that the conditions of lithification are nicely balanced, and that they are readily and frequently disturbed.

Some of these disturbances are due to geographic causes. When a stream enters the sea, there is a tendency for it to be crowded to one side by marine currents, especially during the low stages of the river water, but during freshets the river often breaks through the barriers heaped across its mouth by the sea, and establishes a new channel which it may or may not be able to keep open. In any case, there is a tendency for the stream behind the barrier to shift its channel, especially in the early part of its history, and this shifts the site of the active consolidation of beach sands. In the early development of the coast, the new beaches formed to seaward of the older ones, and this process continued until the cutting of the shores nearly ceased. Some of these newer beaches were hardened, but many of them were not, according to the relation of the beach to fresh-water bodies behind them.

There is, therefore, no more reason for expecting a continuous process of hardening than for expecting all parts of a given bed to harden alike. The hardening is probably now in process in favorable localities. I have no doubt but that it is going on, for example, in the vicinity of Traição and the Lagôa de Sinimbú.

Conclusions regarding the Consolidation of the Reefs.

Stone reefs are formed where there are streams or lakes of fresh water entirely or partially restrained by the beach sands. The new reefs may be formed either in front of the old ones, or in the embayment and estuary behind the older ones. For similar reasons, stone reefs may form behind or landward of the coral reefs. This can only happen, however, in places where marine currents prevent the land-water from interfering with the growth of coral reefs.

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[1] Richard J. Nelson. On the geology of the Bermudas. Trans. Geol. Soc., London, ser. 2, V., p. 123. London, 1840.

[2] Amer. Journ. Sci., ser. 3, XXXIV., p. 163.

The local lithification of the sea beaches is not uncommon, but the most noteworthy instances of lithification on a large scale are those of the northeast coast of Brazil and of the Levant.

The cementing material of the Brazilian stone reefs is chiefly lime carbonate.

The hardening of beach sands may be produced in the following ways: —

1. By carbonated rain-water dissolving out the lime carbonate in the upper portions of calcareous sands and depositing it in the lower portions.

2. By the escape of carbon dioxide from the sea-water when the surf breaks upon the beaches.

3. By the escape of carbon dioxide from sea-water where it is warmed by the tropical sun.

4. By the submarine escape of carbon dioxide about volcanic vents.

These processes may have contributed somewhat to the hardening of the Brazilian reefs, but they do not seem competent to account for them altogether. These theories are especially incapable of accounting for the lithification of beaches behind older reefs.

The distribution of the consolidated beaches of northeast Brazil lead to the inference that the consolidation is directly related to the density of the sea-water. The geology and climatic conditions over the adjacent land are, however, important factors in the hardening of the reef sands. It seems probable that the consolidation of the reef sands would not take place if the rainfall were large enough and constant enough to keep the mouths of the streams open and the water of the streams fresh.

In a region of concentrated rainfall and long drouths the river mouths become temporarily closed, and the abundant aquatic and other life in the lagoons thus formed contributes to the organic acids of the waters, which, upon penetrating the wall or dam of beach sand, first dissolves the lime, and then redeposits it when it comes in contact with the dense sea-water on the ocean side. In this manner some portions of the beaches have been hardened, while others have remained incoherent.

The density of the ocean water is in all probability considerably greater during the dry than during the rainy season, and this would still further hasten the consolidation of the beaches during dry seasons.

The process of beach hardening is not a continuous one, but varies with geographic and climatic conditions. New reefs may be formed behind the older ones on the shores of the estuaries and embayments.

VII.

The Age of the Sandstone Reefs.

If the conclusion reached from the study of the process of consolidation is correct, we may reasonably suppose the formation of the stone reefs has been going on, wherever the local conditions were favorable, ever since the depression of the coast in early Pliocene times. The principal facts that support this view are: —

1st. The stratigraphic relations of the reef rocks to the other rocks of the region.

2d. The relations of the reefs to the adjacent shores.

It is possible that the fossils in the reef rock, in connection with a study of the living fauna of the coast, would bear out this theory, but no study either of these fossils or of the coast fauna has ever been made.

Stratigraphic relations. — The rocks exposed along the coast on and against which the stone reefs are built vary in age from Archaean to recent.

At Bahia, the stone reef rocks abut against very old crystalline schists and eruptives; at Cape Santo Agostinho they rest directly against granites assumed to be of Archaean age. At many places waterworn and subangular fragments of the iron-cemented sandstones, so common in the weathered Cretaceous and Eocene Tertiary rocks, are common in the reef rocks. Mention will be found of some of these instances under the detailed descriptions of the reefs in Chapter III.

At Riacho Doce in the State of Alagôas, Tertiary (?) shales are exposed upon the beach. These shales, and the granite boulders accompanying and underlying them in some places, have patches of coral reefs lapping over them, and at two places on this beach I observed the reef sandstone on top of the coral reef. One of these exposures is two hundred metres long. At another place the sandstone reef lies directly upon the Eocene rocks.

The stratigraphic relations of the reefs to the Tertiary beds are matters of conjecture rather than observation. There are, to begin with, but few places along the coast where both Pliocene beds and sandstone reefs occur side by side. One of these is at Rio Formoso, Estado de Pernambuco, where the stone reef is one and a half kilometres from the Pliocene exposures on the Praia da Gamella.

At Serinhaem the Tertiary is exposed on the side of the river at the town, and the reef does not touch them.

At Mamanguape the relations of the Tertiary sandstones and the reefs appear to be as shown in Figure 8, page 29.

At Rio Formoso and Serinhaem the Tertiary is considerably higher than the sandstone reef; at the Mamanguape locality, there seems to be but little or no difference of level.

On the shore of the mainland opposite Catú on Itaparíca Island, Bahia, there is a long low sandstone bank that I take to be Pliocene. There are no stone reefs near this, however.

At other places the relations of the stone reefs to rocks of known age are not shown, but there are no facts in my possession that are not in accord with the theory that the stone reefs are newer than any other consolidated sedimentary beds along the Brazilian coast.

Physiographic relations. — The relation of the reefs to the adjacent shores is accepted as evidence of the recent date of some of the reefs, while the process of their formation strongly suggests, if it does not prove, that the low, flat lands behind the stone reefs are underlain by other stone reefs. Seashores are rarely at a standstill; they are either being cut away or built out. Their elevation, as compared with that of the land and their marginal position relative to the flat country behind them, show that the reefs and the flat lands are genetically related, and that they are of about the same age. These flat lands are partly recent deposits; but they also extend back into the Pliocene. Their origin is discussed in Chapter V. One of the most striking features of the external stone reefs is their proximity to and parallelism with the shores behind them. If a stone reef had been in existence for a long time, speaking geologically, it would have been either obliterated by the encroaching sea, or it would have been buried under the encroaching land.

The fossils in the reefs. — The fossils found in the reef rock, so far as they are now known, are the remains of animals now living in the seas along side of the reefs. At Pernambuco, Rio Formoso, and Mamanguape the most common fossils are the shells of "mariscos" (a species of

Venus) which are as fresh and bright as the shells upon the present beach.[1] These bivalves are much sought for as food. They are taken in the bays behind the reefs and near the shores, and also on sandbars. Their dead shells are abundant on the present beaches.

The *Venus*, so abundant in these rocks, lives in the sand; but the animals stand on end about five centimetres below the surface, and the living shells are covered with horny epidermis. The shells found in the rocks are always, so far as I have yet seen, without epidermis, the valves are apart, and the shells usually have the convex side upward. These facts show that the shells, as they occur in the rock, are not in the places where the animals lived.

Several other shells, mostly gasteropods, are found in the rocks of the stone reefs, but without exception they are forms that are often found dead on the beach, or living in the shallow water near shore.

The littoral character of the shells found in the reef rock should not be overlooked, for Liais thinks some of the reef beds were formed at sea ("*formé au milieu de la mer*"), and that they have been displaced since then.[2]

Barão de Capanema speaks of seeing fragments of pottery imbedded in the rock near the lighthouse at Bahia.[3]

Hartt thinks Pissis and Darwin "in all probability" mistook the stone reefs for Tertiary rocks.[4] This seems to be an unwarranted assumption, for in Pissis's paper there is no specific mention of the reef rocks,[5] while Darwin, in his paper on the Pernambuco reef, assigns to them a recent date.

Although one gets the impression that the fossils of the stone reefs are all recent, the fact should not be overlooked that these fossils have never been systematically studied in connection with the existing fauna. Moreover, the reefs one sees, and to which access is easiest, are all the new outer reefs, and usually the latest ones formed, while the old reefs are to the landward, and usually near the bases of the hills that formed the old shore lines.

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[1] One sometimes hears the suggestion that the fresh colors of the reef fossils is evidence of the recent age of the sandstone reefs. This may be true to some extent, but these colors alone could not be accepted as evidence. We have rocks of Jurassic age even, whose fossils still preserve their bright colors.

[2] L'Espace Céleste, p. 545, 548.

[3] Trabalhos da Commissão Scientifica de Exploração. Rio de Janeiro, 1865. Introducção, I., p. CXXXVII.

[4] Geol. and Phys. Geog., p. 269.

[5] Mém. Inst. France, 1842, X., p. 398.

Conclusions.

1. The fossils and existing coast fauna are as yet too little known to throw much light on the question of the age or ages of the reefs.

2. The stone reefs are built against rocks of all ages from Archaean to recent.

3. The only rocks with which they seem to be interbedded are Pliocene and recent.

4. It is therefore inferred that the formation of the stone reefs began in early Pliocene times, and that it has gone on down to the present time.

VIII.

Annotated Bibliography of the Stone Reefs of Brazil.

Angelo, F. Michael, and **Carli, Denis de.** A curious and exact account of a voyage to Congo in the years 1666 and 1667. Pinkerton's collection of Voyages and Travels, London, 1814, Vol. XVI. 152.

The authors of this account touched at Pernambuco on their way to Africa. In the first part of it Angelo speaks of "a wall . . . which credible people say is natural, running three hundred miles, one part of it enclosing the harbour."

Anonymous (?). Sommier Discours ouer den Staet vandee vier geconquesteerde Capitanias Parnambuco, Itamarica, Paraiba ende Rio Grande inde Noorderdeelen van Brasil.

This paper is a separate from the "Bijdr. en Meded. II." The article is said to be from the "Archief van Hilten," and is dated January 19, 1608.

Speaking of Pernambuco (p. 306) the author says: "This haven is wonderfully situated, for it has a continuous stone wall just like a dike, forty paces or more in width, and from the bar it extends for more than a mile in front of Recife, and on the inside it makes the harbor big enough to hold many ships."

Anonymous. *Nautical Magazine* for July, 1861, p. 345–349, contains an article quoted from the *Moniteur de la Flotte.*

It says the Pernambuco reef is made by "coral insects." References to schistosity, vertical dips, and parallelism of the reefs with the mountain systems of Europe suggest that the article may have been written by M. Liais.

Anonymous. Pacific Line Guide to South America, containing information for travellers and shippers to ports on the east and west coasts of South America. London, 1895. 8°, 151 pp.

On p. 31 it is stated that the harbor of Pernambuco "is formed by the recife, a singular coral reef which borders the shore, more or less from Bahia to Maranham, a distance of nearly a thousand miles."

Auchincloss, W. S. Ninety days in the Tropics or Letters from Brazil. Wilmington, Del., 1874, p. 21.

This writer says, "the natural harbor is formed by a coral reef running parallel with the shore."

Ball, John. Notes of a naturalist in South America. By John Ball, London, 1887.

On page 351 this writer says that Pernambuco is "separated from the open roadstead by a coral reef several miles in length." The author was at Pernambuco on board a transatlantic steamer, but, so far as I can learn, did not personally examine the reef.

Barlaeus, Caspar. Res Brasiliæ imperante Illustrismo D. I. Mauritio Nassoviæ, etc. Principe, per C. Barleum. Accedit G. Pisonis Tractatus de Aere, Aquis et Locis. Clivis.

(This work has also the following title by which it is commonly known: Rerum per Octennium in Brasilia.) Editio secunda. Clivis, 1660. (The "dedicatio" is dated April 20, 1647.) The first edition of this work was published at Amsterdam in 1647; the present references are to the second edition.

Piso's description of the reefs is given on p. 584–585. On page 248 is a plan of the city and reefs of Pernambuco, and a view of the town and reef taken by the Dutch artist F. Post from the south, and looking toward the city and the northern end of the reef. (Page 66): "Between Rio Biberibe and the ocean is a very narrow sandy tongue of land about a mile (?) long. . . . Where it comes to an end is the so-called *recife* (*Reciffa*) or receptacle (*Receptus*),[1] probably so named because between this tongue and another insular oblong tract called the stone reef ships can enter." (p. 248–249.)

It should be noted that Barlaeus was never in Brazil, and that his information was largely at second hand,[2] partly from Jean de Laet. The work is important in this connection largely on account of the beautiful drawings by Post.

Barrow, John. See **Malte-Brun.**

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[1] Barlaeus is in error here. *Recife* is the Portuguese word for reef, and the name of the city was unquestionably taken from the reef, not from the form of the harbor.

[2] Historia das lutas com os Hollandezes. Pelo Barão do Porto Seguro, Lisbôa, 1872, p. 176.

Bayern, Therese Prinzessin Von. Meine Reise in den Brasilianischen Tropen, von Therese Prinzessin von Bayern (Th. von Bayer). Berlin, 1897.

This writer passed through the São Roque channel in a small coasting steamer, and mentions the reefs there, but does not say whether they are stone or coral reefs (p. 204). She notes the interesting fact that at Touros the palms have their trunks all leaning toward the northwest on account of the predominating direction of the winds (p. 204). The Natal reef is spoken of as a stone reef (p. 205). A photograph of the Pernambuco reef is reproduced and the reef mentioned as being of sandstone (p. 213).

Belmar, A. de. Voyage aux Provinces Brésiliennes du Pará et des Amazones en 1860, Londres, 1861, 42.

"Toute la côte est défendue par cette longue cordillère sous-marine qui, de Santa Catherina jusqu'au Pará, cotoie le littoral américain." By this submarine mountain chain is meant the stone reef at Pernambuco.

Bérenger. See **Fournié.**

Caminha, Pero Vaz de. Carta de Pero Vaz de Caminha published in a foot-note in the Corografia Brazilica de Manuel Ayres de Cazal, Rio de Janeiro, 1817, Vol. I. 12 to 34. It is also republished in modern Portuguese in the Revista do Instituto Historico do Brazil, 1877, XL. pt. II., p. 13–37.

This letter of Vaz de Caminha, one of the companions of Cabral, the discoverer of Brazil, was dated at Porto Seguro, May 1, 1500. It gives no specific information about the reef, but it contains the earliest record of its existence, — that at Porto Seguro, — which he speaks of as "a reef having a very good and secure port inside of it." (p. 15.)

Capanema, Guilherme S. de. Trabalhos da Commissão Scientifica de Exploração I., Introducção, Rio Janeiro, 1862, p. cxxi-cxxii.

This paper is the preliminary report of the geological section of the commission. The author examined the reef rock near the lighthouse at Bahia. He says: "There is a psammite there still in process of formation; the rock is sand cemented with lime, possibly derived from the corals whose heads are destroyed as fast they emerge. This rock, which is identical with that of the Peloponnesus and of the Antilles, is one more proof of the elevation of our coast, for while it is of submarine origin, it is broken above high-tide level. Instead of palaeontological documents, it contains some that show the very recent date of the consolidation of these sands; I refer to bits of broken pottery."

Of the Pernambuco reef he says that bits of lava have been thrown upon the reef from which it has been stated that the reef is of igneous origin; this he says should deceive no one.

Cazal, Ayres de. Corografia Brazilica. Rio de Janeiro, 1817, II. 169

The author says the bay at Cururipe is protected by a reef, but whether coral or stone, he does not say. The reef in front of Pernambuco, he says, extends from Bahia to Cape St. Roque (173) parallel with and a short way from the shore; that it is at the level of high tide, and six feet above low tide, perpendicular on the inside and sloping outward.

Dapper, Dr. O. See **Montanus, A.**

Darwin, Charles. On a remarkable bar of sandstone off Pernambuco on the coast of Brazil. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science. Oct., 1841, XIX., p. 257–261.

This is the earliest geological description of the Pernambuco stone reef. It contains a cut showing a cross-section of the reef. He says that "it consists of a hard pale-colored sandstone, breaking with a very smooth fracture and formed of siliceous grains cemented by calcareous matter. Well-rounded quartz pebbles from the size of a bean, rarely to that of an apple, are imbedded in it, together with a very few fragments of shells."

He thinks that its having withstood the action of waves so long is "owing to the protection afforded by the thin coatings of Serpulae and other organic beings." He thinks that it is formed by the agency that made the linear islands on some coasts, such as the Gulf of Mexico. It is suggested that if the nucleus of a sand spit were once consolidated, a small change of level or of currents might cause the loose sand to be washed away, leaving such a structure as the reef, which might be preserved from complete destruction by protection of animals.

Darwin, Charles. Journal of researches into the natural history and geology. Voyage of the Beagle. New York, 1878, p. 198–199.

Mr. Darwin here remarks that he doubts "whether in the whole world any other natural structure has so artificial an appearance." He expresses the opinion that the reef was formed by the consolidation (through percolation of calcareous matter) of a long spit or bar of loose sand, and afterwards gradually upheaved. "The oldest pilots know of no tradition of any change in its appearance." This durability he attributes to the coating of calcareous matter on its seaward face.

Darwin, Charles. The structure and distribution of coral reefs. Supplement on a remarkable bar of sandstone of Pernambuco on the coast of Brazil. Third ed., London, 1889, p. 277–280. Second ed., p. 265–267.

This is a slightly modified reprint, without the cut, of the article originally published in the London, Edinburgh, and Dublin Philosophical Magazine, Oct., 1841, p. 257–261.

Denis, Ferdinand. Brésil. Paris, 1863, p. 253.

Denis says that the reef extends from Bahia to Cape St. Roque, and that at Pernambuco it is at the level of high tide and six feet above low tide. He quotes the following from a manuscript of L. F. Tollenare: "The rock composing it is a very hard sandstone which encloses a great many perfectly preserved shells."

Findlay, Alexander George. A sailing directory for the Ethiopic or South Atlantic Ocean. 9th ed., London, 1883.

"The Recife, a singular ridge of coral rock which borders the coast, has been previously noticed. It extends, more or less, all the way from Point Toiro, or Calcanhar (lat. 5° 9½′), to the Morro of St. Paulo (13° 23′), and its intervals form the entrances to the various ports" (p. 378). The stone reefs are not distinguished by this author. After this general description they are all spoken of as "reefs," including the most notable of the stone reefs. He adds, however, regarding that at Pernambuco: "Mr. Cowper, formerly H. M. Consul at Pernambuco, considers that this reef is of coralline origin, and that when it has reached the surface, the insects abandon their labour, and the interstices of their beautiful fabric become choked with sand and broken shells, which after a time become incorporated with it, and form in appearance what is a rough sandstone" (p. 386).

Fletcher, J. C., and **Kidder, D. P.** Brazil and the Brazilians. 9th ed. London, 1879, p. 513, 516. On page 516 is quoted the description given by Dr. Kidder, which see.

On page 513 is given the same poor woodcut of the entrance to Pernambuco as that first published in Hadfield's Brazil, p. 98.

Fournié, Victor, and **Béringer, Émile.** Mémoire sur le port du Recife. Uitgegeven van wege het "Aardrijkskundig Genootschap." Bijblad, No. 8. Amsterdam and Utrecht, 1881.

The second part of the *mémoire* by M. Béringer is upon "Le port de Pernambuco et la ville du Recife au 17e siècle," and includes the information the author was able to gather in Holland regarding the port, reef, and city of Recife during the occupancy of the Dutch from 1630 to 1654. This paper is accompanied by an interesting map showing the changes thus found to have taken place between the middle of the seventeenth century and 1876, when this map was made. It gives a brief résumé of the physical history of Pernambuco during Dutch occupation. "As an example of the rather strange topographic inexactness," he cites, "the pronounced bend of the reef, . . . a bend which could not have existed, as one may see, aside from other proofs, by glancing at the panorama of the port drawn by Post in Barlaeus' history."

Francisco de Brito Freyre. Nova Lusitania, Historia da guerra Brasilica. Lisboa na officina de Joam Galram. Anno 1675. Livro quarto, sec., 339, p. 176.

Speaking of the city of Recife, the author says: "The impetus of the waves is broken by the chain of a very remarkable reef which rises slightly above and is occasionally covered by water, continuing a great number of leagues, which, though cut by nature, is almost as even as artificial walls."

Gama, Jozé Bernardo Fernandes. Memorias Historicas da Provincia de Pernambuco. Pernambuco, 1844–8.

Volume III. contains a plan of the city and reef of Pernambuco, after Barlaeus (1647). Volume IV. has another plan after Col. C. J. de Neimeyer on which the position of the reef is shown by a straight line.

Gandavo, Pero de Magalhanes de. Histoire de la Province de Sancta-Cruz que nous nommons ordinairement Brésil. Lisbonne, 1576. (Voyages, relations et mémoires originaux de L'Amerique. Par Henri Ternaux. Paris, 1837. II.)

Speaking of the Pernambuco reef, this author says: "At one league to the south of the Olinda colony, a reef or chain of rocks forms the port" (p. 37).

Gardner, George. Travels in the Interior of Brazil, principally through the northern provinces. London, 1846, p. 80, 94, 103, 104, 154.

At Pau Amarello, a small fishing village between Pernambuco and Itamaricá, the reef is about a mile from the shore, and is there not concealed by high water. Gardner noticed a strong resemblance between the reef rock and the sandstones at Rio Formoso, and thought he "could trace, at low water, a rocky connection between the reef and the rocks of which the hills were composed. It is more probable that the reef owes its origin to the decay of the rock between it and the shore." He considered the rocks at Rio Formoso the same as the Cretaceous rocks of Ceará, and he therefore must have considered the stone reefs to be of Cretaceous age.

He notes a reef at Aracatí (154), north of Cape St. Roque.

Affonso H. de Souza Gomes. Relatorio sobre o melhoramento do porto do Natal, apresentado ao Ministro e Secretario dos Negocios da Agricultura. . . . Natal, 1890. 10 pp. and maps.

This report says the Natal reef is of sandstone like that of Pernambuco, hardened, as Hartt explained, by lime derived from shells in the beds. The rock opposite and inside the bar — Baixinha — he says is the same as the rock of the reef. The author speaks of one single continuous reef along the coast, but he thinks the weakening and breaking of it due to the river current. The map of Hawkshaw is reproduced on a small scale.

The greater part of the paper is necessarily taken up with suggestions regarding the improvement of the port.[1]

Graham, Maria. Journal of a voyage to Brazil. London, 1824.

Mrs. Graham visited Pernambuco in 1821, and examined the reefs. She says (p. 101) that "the rock of which the reef is formed, is said to be coral; but it is so coated with barnacle and limpet above barnacle and limpet that I can see nothing but the remainder of these shells for many feet down, and as deep into the rock as our hammers will break. . . . The reef is certainly one of the wonders of the world; it is scarcely sixteen feet broad at top."

According to Maria Graham (p. 101), the Pernambuco reef was artificially mended by Count Maurice during the time of the Dutch occupancy. The lighthouse was just being put up on the reef when she went there in 1821.

Guelen, Aug. de. Briefve relation de l'estat de Phernambucq, dédié à l'Assemblée des Dix-neuf pour la très noble compagnie d'West-Inde, par A. de Guelen. Amsterdam, 1640. 4°, 22 ff. (Not seen; title from A. L. Garraux' Bib. Bras. Paris, 1898.)

Hadfield, William. Brazil, the River Plate, and the Falkland Islands. London, 1854.

Speaking of Pernambuco, he says (p. 101): "The harbor is quite a natural one, formed by a reef of coral rocks already described as running along the whole extent of the Brazilian coast, and supposed to be continued inland, where the coast projects beyond the line of the reef." The woodcut of the reef on p. 98 is quite worthless. Elsewhere he says (p. 96) that the reef "extends along the whole coast of Brazil from Cape St. Roque to the Abrolhos near Rio de Janeiro, and is of the same hard coral nature."

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[1] For a copy of this rare report I am indebted to my friend, Dr. José de Berredo, Engineer, Natal.

Hartt, Ch. Fred. Geology and physical geography of Brazil, Boston, 1870.

Professor Hartt notes (p. 62) the occurrence of a bit of consolidated beach of "quartz sand cemented by carbonate of lime," just south of Guaraparý, Province of Espirito Santo. At Barra Secca, about 30 miles north of the mouth of Rio Doce, he found similar consolidated sands uncovered at low tide (p. 107). Again at As Pedras (Espirito Santo), he found the same kind of sandstone on the sea beach (p. 114). "The arrangement of the materials in this sandstone is precisely like that of the beach, and this formation is only the lower part of a beach ridge which has been cemented by the lime of shells, etc." The rock is very hard; it is in places broken into blocks which lie tilted about. He suggests (p. 115) the probability of the waters of lakes behind the beach percolating through the sands, and that this might have been an agency in its solidification.

He speaks of the stone reefs of Brazil in general (p. 185–187), shows how coral and stone reefs have been confused on the Brazilian coast, and how many erroneous statements have passed current regarding them. The Porto Seguro reef is described, and a cross-section given (p. 228–229); this reef is said to be remarkably straight, and its height and width even, while it overhangs on the land side. The solidification is said to have extended "many feet below low-water level;" in places it is coated on the outside by corals; the lamination slopes seaward; the rock is sandstone with calcareous cement. The stone reef at Santa Cruz is described (p. 233), and a sketch map given showing its location. He speaks (p. 342–344) of the consolidated beach sands east of the lighthouse at Bahia; these sandstones dip seaward, and occur from Bom Fim to Rio Vermelho. They contain fresh shells. The hardening is explained as produced by the solution of carbonate of lime by rain and sea-water from shells in the sands, and redeposition at a lower level. Copious rains, he thinks, aid this work, also waters from marsh lands; later the loose material is removed by storms or freshets. The Rio Vermelho reef is described and is said to be somewhat elevated. The same section is given (p. 344) as that for Porto Seguro (p. 229). These rocks, he says, are quarried for building purposes.

The Pernambuco reef is described (p. 434) as the same as those of Porto Seguro, Sta. Cruz, and Bahia, and a small map shows its general location. He presumes that Barlaeus's map of Rio Parahyba shows a stone reef; the reef at Rio Grande do Norte is put down as stone (p. 455) with a small map from Almeida.

Hartt, Ch. Fred. Relatorio preliminar de trabalhos da Commissão Geologica na Provincia de Pernambuco. Rio de Janeiro, 1875.

Professor Hartt states (p. 4–5), in speaking of the stone reefs, that his studies of them prove that the earlier theory advanced by him is correct, and the idea that the Pernambuco reef extends north and south for long distances is entirely wrong. These reefs he considers local. That south of Cape Sto. Agostinho is remarkably regular. Such reefs are found in various stages of development; in some places there are two or three of different ages, separate, but parallel. The later consolidated beaches are thin and rest in loose beach sand.

Hartt, Ch. Fred. Algumas considerações sobre o recife de Pernambuco. Pelo Professor Carlos Frederico Hartt, Chéfe, etc. Revista do Instituto Polytechnico. Tomo V. parte 2, p. 21–26. Rio de Janeiro, 1875.

This article is dated March, 1876. It contains the same facts as those given in the *Relatorio Preliminar* cited in the preceding article.

Hawkshaw, Sir John. Melhoramento dos portos do Brazil. Publicação official. Rio de Janeiro, 1875.

This report, in Portuguese and English, contains descriptions of all the more important Brazilian ports, among them those of Pernambuco and Rio Grande do Norte. At Pernambuco borings were made upon the reef, the first and only ones ever made. These borings are of great importance in understanding the geology of the reefs; they show (p. 15) the hard sand rock to be three or four metres thick; below this are layers of sand, clay, shells, etc.

A rock reef is mentioned at Ceará (p. 91). Among the charts accompanying the report is one showing the reef at Rio Grande do Norte, and one at Pernambuco; the latter also gives the details of the borings on the reef.

Hawkshaw, J. Clarke. Notes on the consolidated beach at Pernambuco. Quar. Journ. Geol. Soc. 1879, XXXV., p. 239–244.

Mr. Hawkshaw was an assistant of Sir John Hawkshaw, who had the borings made through the stone reef at Pernambuco in 1874. His paper gives the section disclosed by the boring upon the reef opposite the marine arsenal. He raises the question whether the existence of a bed of hard rock below the reef can be regarded as evidence of an older beach consolidated when it was at the surface. He is of the opinion, however, that the coast has recently risen. He says the cementing material is carbonate of lime. He is of the opinion that these reefs have been formed from long sand ridges with lagoons behind them; that "the percolation of land-water charged with carbonic acid derived from the decayed vegetable matter in these lagoons through the sand ridges will account for the formation of the beach rock, the water taking up and again depositing the carbonate of lime of the shells." "The flood-level of the lagoon will determine the level of the upper surface of the beach rock; and that of the lower surface would be determined by the cessation of the consolidating action at the level at which the sand was saturated by sea-water."

Henderson, James. A history of the [*sic*] Brazil; comprising its geography, commerce, etc. London, 1821, p. 382.

In speaking of Pernambuco, it is stated that "A recife, or chain of reefs, which extends itself from the entrance of Bahia to Cape St. Roque . . . in no part appears so much like an operation of human art as here. It is prolonged for the space of a league in a direct line with and about two hundred yards from the beach, having the aspect of a large flat wall, being always above the level of the sea, and at low water six feet is discovered." It is "perpendicular on the land side, and gradually declining on the other."

Hinchcliff, Thomas W. South American sketches; or a visit to Rio de Janeiro [*sic*], the Organ Mountains, La Plata and the Paraná. London, 1863.

On p. 11, he calls Recife "a coral reef, which extends, with few interruptions, like a regular sea-wall, for nearly four hundred miles along the coast of Brazil."

Keller, Franz. The Amazon and Madeira Rivers. New York, 1874.

This writer, in speaking of Pernambuco, says that: "On the remarkable coral reef that protects the port are a fine new lighthouse and a quaint old watch-tower. . . . This coral reef . . . is extending all along the coast of Brazil" (p. 26).

Kidder, Daniel P. Sketches of residence and travel in Brazil. 2 vols. Philadelphia, 1845. II. 123.

Dr. Kidder states that the rock of the reef of dark brown external appearance is hard yellowish sandstone containing bivalve shells; he refers to its "extending along the greater portion of the northern coast of Brazil." The top of that at Pernambuco, he says, "is scarcely visible at high tide." "At low water it is left dry, and stands like an artificial wall."

Koster, Henry. Travels in Brazil. 1st ed. London, 1816. 2d ed. London, 1817.

Koster lived in the Province of Pernambuco from 1809 to 1815. In Vol. I. he gives a plan of the port of Pernambuco, showing the reef, furnished "by an English gentleman resident at Recife." It shows the reef curving toward the land. "The reef of rocks . . . continues along the whole coast between Pernambuco and Maranham, and in some parts it runs at a very short distance from the shore, and in this case is usually high, remaining uncovered at low water, as at Recife; but in other places it recedes from the land and is then generally concealed. It has numberless breaks in it, through which the communication with the sea is laid open." (p. 13–14 of 2d ed.)

Laet, Jean de. L'histoire du Nouveau Monde ou description des Indes occidentales, contenant dix-huict Liures. Par le Sieur Iean de Laet, d'Anuers. Leyde, 1640.

This writer, one of the directors of the West-India Company, lived in Pernambuco from the arrival of the Dutch in 1630 until 1636.

Speaking of Olinda, he says (p. 530): "The port of this city . . . is closed by rocks and banks as if by a bar (which borders the coast of Brazil for many leagues) so that large ships enter only by a narrow passage." Again (p. 533), he says: "Almost all the coast of Brazil is bordered by rocks which form an almost continuous line, which rocks are exposed at low tide, are about nine perches of ten feet wide and often more and stand like a bar or rampart . . . cut at many points."

Laet, Joannes de. Historie ofte Iaerlijck Verhael vande Verrichtinghen der Geoctroyeerde West-Indische Compagnie Zedert haer Begin tot het eynde van't jaer 1636. Leyden, 1644.

At p. 382 he gives a very good map of Cape St. Agostinho, showing the stone reef south of there. A map is also given (p. 364) of the mouth of the river at Rio Grande do Norte showing the stone reef.

Liais, Emm. L'espace céleste ou description de l'univers accompagnée de récits de voyages entrepris pour en compléter l'étude. Paris. 2me edition. (1881.) (First edition, 1865.)

This work contains the only sketches published, so far as I can learn, of the stone reefs immediately south of Cape Santo Agostinho (p. 545, 546). Of the stone reef in general it is said that it is higher than high tide at but few points. It is a foliated sandstone of quartz and feldspar with fragments of shells hardened by a silico-calcareous cement. He notes that the reef is not one unbroken wall, but is made up of a number of straight parallel lines, never curving. "The rock of the reef bears evidence of displacement since its formation. Its beds dip seawards at an angle of about forty degrees. At some places the dip is not so much, but at others it is more marked, and south of the Serrambi point I have even seen a part of the reef standing on edge." He is of the opinion that these sands were deposited in the sea in horizontal beds and subsequently displaced by crust movement. He speaks of the protection of the exterior by polyps. He evidently adheres to an earlier opinion about the direction of the reef, for he says (p. 544), that "this question is . . . connected with one of the most remarkable facts in the history of our planet, namely, the alignment of the surface wrinkles upon the arcs of a great circle extending over immense distances."

The Pernambuco reef is said to bear N. 20° E., and to be parallel to the direction of the western Alps (p. 548). The reef rocks are considered to be of later age than the hills of the coast (p. 547), and not far removed from the modern epoch. He does not think the rock is now forming (p. 548).

This writer was stationed at Olinda for eight months (1859–60) as an astronomer of the Imperial Observatory, and his observations are based upon personal observations (p. 279).

Liais, Emm. Inclinaison des couches de roches arenacées modernes des côtes du Brésil; extrait d'une lettre à M. Élie de Beaumont. Compt. Rend. 1860, L. 762–3.

This letter is dated Olinda, March 8, 1860. The author says, "The rock of the reef that borders the coast of America is a quartzose sandstone filled with shell fragments;" that its structure is grossly schistoid, and the beds inclined at an angle of 35° to 40°, with the strike N. 20° E.

The reef is made up of fragments of straight parallel lines, but not always lying in the same prolongation, "and as the coast is modelled on the reef . . . its general direction oscillates a little about that of the reef." He refers to the eroded condition of the reef, and to the polyps on its outside face, and says the quartz grains and shells are held together by a siliceous lime cement.

The most remarkable point in this letter is that the author finds in the direction of the reef confirmation of Élie de Beaumont's theory of the parallelism of structural features of the earth's crust; that the reef follows these lines even more closely than the coast-line, and that it agrees "with the direction of the Western Alps."

Liais, Emmanuel. Climats, géologie, faune et géographie botanique du Brésil. Paris, 1872, pp. 256–261.

The reefs are considered as proof of very recent elevations along the Pernambuco coast (p. 256). "The reef rock is a sandstone composed of quartzose grains and of fragments of shells hardened by a siliceous calcareous cement, and presenting a schistoid structure." Some of the shell fragments he found petrified. The beds of rock dip seaward, he says, at an angle of 35° to 40°. Near Serrambi, and south of there, he says, he saw on the shore a part of the reef standing vertically. He states that the reef is never crooked ("*Jamais il ne se courbe*"). The surface decay is noted, and the protection given by polyps. He repeats his earlier statement that the coast-line is "modelled on that of the reef." In age he thinks that the reef marks the close of the Quaternary and shows the last elevation of the coast.

Lisbôa, Alfredo. Memoria descriptiva e justificativa do projecto do melhoramento do porto do Recife . . . por Alfredo Lisbôa . . . em 1887. Pernambuco, 1887.

This report has a very good map of the northern end of the reef. The description of the Pernambuco reef is short but excellent. He observes that the reefs of the coast are not continuous; that they are never higher than the highest tides; he gives the direction as S. 19° 32′ W. (true), with a length of three thousand one hundred and twenty metres to the Barreta das Jangadas, and a width of twenty to sixty metres. He notes the composition correctly, and thinks the sands hardened by lime derived from the shells (p. 6–8). On p. 98–100, the author quotes the opinion of Hartt in regard to the origin and nature of the reefs of Brazil.

Malte-Brun, M. Universal geography, or a description of all parts of the world. III., p. 389 and 401. Philadelphia, 1827.

Malte-Brun says the coast of Brazil "from Maranhão to Olinda is bounded by a reef of coral, resembling in many places an artificial mole." He says also that the harbor of Porto Seguro "is sheltered on all sides by steep coral rock."

Malte-Brun. Voyage à la Cochinchine par les Îles de Madère le Brésil et l'Île de Java (etc.). Par John Barrow . . . Traduit de l'Anglais avec notes et additions. Par Malte-Brun. 2 vols. Paris, 1807.

The fourth Chapter, from which the following is taken, was written by Malte-Brun. Tome I., p. 156, says: "The northern coasts of Brazil from Pará to Olinda are bordered by a reef . . . which at many points resembles an embankment or dike. It is without doubt of coral rock. The inhabitants of Olinda and of Parahyba use it to build their houses. Similar reefs form all the ports and estuaries of the province of Porto Seguro; they look like a natural wall along the coast." The foot-notes lead one to suppose that these observations are taken from the writings of Piso and Barlaeus.

Mansfield, C. B. Paraguay, Brazil and the Plate. Letters written in 1852-1853. Cambridge, 1856, p. 27-29.

A small sketch is given showing the reef and harbor at Pernambuco. "This reef, which seems to be about five or six feet across, runs along the coast for some three hundred miles. . . . It is formed of sandstone, full of pebbles and shells, and stands up just like a wall."

Maximilian, Prince of Wied-Neuwied. Travels in Brazil. London, 1820.

The author travelled (1815-1817) along the coast from Rio de Janeiro to Bahia. Just south of the mouth of Rio do Frade (South of Porto Seguro) he found (p. 259) "at very low water extensive banks of sand and calcareous rocks, which stretch far into the sea, and which have probably been chiefly produced by zoöphytes. Their surface is divided into regular parallel clefts." (French ed. Paris, 1821. II., p. 72.) He mentions the reef at Porto Seguro (265), and another across the mouth of Rio Santa Cruz, five leagues north of Porto Seguro (p. 268. French ed., II., p. 87-88).

Montanus, Arnoldus. De Nieue en Onbekende Weereld of Beschrijving van America en 't Zuid Land, Vervaetende d'Oorsprong der Americaenen, etc. Door Arnoldus Montanus t'Amsterdam. By Jacob Meurs, 1671.

The German translation of the above, erroneously credited to Dr. O. D(apper), has been examined. It is entitled Die Unbekante Neue Welt, oder Beschreibung des Welt-teils Amerik und des Sud-Landes, etc. Durch Dr. O. D. Zu Amsterdam. Bey Jacob von Meurs, 1673.

Mention is made of the reefs at many places along the coast. Opposite page 542 is a copper-plate giving a view of the Pernambuco stone reef from the south end. This plate is probably from the first edition of Barlæus, however, and the drawing was probably made by the Dutch artist Francis Post between 1630 and 1654. A part of the same view, somewhat modified, is reproduced in Varnhagen's Historia Geral do Brazil, 2d ed., I., p. 504.

Moreav, Pierre. Histoire des derniers trovbles dv Brésil entre les Hollandois et les Portvgais. Paris, 1651. (Description du recif.)

"It is to be observed that Brazil from one end to the other, said to be a distance of a thousand and fifty leagues, is bordered its whole length by a large long flat rock usually from ten to twenty paces wide, in the sea and a gun shot, more or less, from the shore, as high as a pike or more, uncovered when the tide is out but not otherwise because it is all covered." This work has a rather fantastic sketch, map, or diagram of the reef and of the region between Olinda and Affogados (p. 3).

Mouchez, Ernest. Les côtes du Brésil, description et instructions nautiques. Première section : du Cap Saint Roque a Bahia. Paris, 1874.

This author says (p. 15, also p. 23) of the coast between Cape St. Roque and Rio São Francisco, that "a coral reef borders all the coast from one to two miles out," and that south of the São Francisco, "the reef ceases where sand dunes begin." The reef is said (p. 23) not to be higher than high tide, and that it "is sometimes of groups of corals more or less distant from each other, as at Cape St. Roque, and at other times it forms a veritable wall parallel with the shore, as at Pernambuco."

Reefs are spoken of at many of the various points at which they are known to occur, but no mention is made of stone reefs as such.

Nieuhof, Johan. Gedenkweerdige Brasiliaense Zee-en Lant-Reize. Amsterdam, 1682.

This author derives Pernambuco from *Inferno en bokko*, which he understands to mean the "mouth of hell," on account of the rocks about the harbor's mouth (p. 13). Upon this explanation of the word Pernambuco, see foot-note under "Rolt." This is not properly rendered in his English edition.

On page 15 he gives the description quoted under the next title.

Nieuhoff, John. Voyages and travels into Brazil, with a particular account of all the remarkable passages that happened during the author's stay of nine years in Brazil (first half of the seventeenth century). Vol. XIV. (p. 697–881) of Pinkerton's collection of Voyages and Travels. London, 1813.

The Pernambuco reef is described on pages 708–709. He says that "the whole coast of Brazil is, from one end to the other, surrounded with a long, thick, and flat ridge of rocks, which in some places is twenty and in other thirty paces broad; however, there are certain passages in this ridge through which the ships approach the shore and some few places, where this ridge is not to be found at all." He says that "at low tide most of those rocks appear above water; though the tide never fails to cover the same." He generally speaks of the reef as the "stony reef."

For the original edition of Nieuhof's book, see the preceding title.

Nieuhoff, John. Voyages and travels into Brazil and the East-Indies: containing an exact description of the Dutch Brasil . . . with a most particular account of all the remarkable passages that happened during the author's stay of nine years in Brasil (1640–1649). Translated from the Dutch original. London, printed for Awnsham and John Churchill at the Black Swan in Pater Noster Row, 1703, 4°, ill.

The author, who was very familiar with the northeast coast of Brazil, states (p. 9) that "the whole coast of Brasil is from one end to the other, surrounded with a long, thick and flat ridge of Rocks, which in some places is 20 and in others 30 Paces broad: However there are certain Passages in this Ridge through which the Ships approach the Shoar, and some few Places, where this Ridge is not found at all." He also states that at "Low-Tide most of those Rocks appear above Water; though the Tide never fails to cover the same." Of the reef at Pernambuco he says: "It is very flat, without any Prominences."

Olfers, J. F. M. v. Ueber das niedrige Felsenriff der Küste von Brasilien. Archiv für Mineralogie, Geognosie, Bergbau und Hüttenkunde. Herausgegeben von Dr. C. J. B. Karsten. IV., p. 173–183. Berlin, 1832.

This is the earliest paper written by a geologist, and is one of the most important upon the stone reefs of Brazil. The author distinguishes between the stone and the coral reefs, and describes the rock of the stone reefs so that there can be no misapprehension regarding their character. He expresses the opinion that these reef rocks are of Tertiary age, but he confuses them with the Tertiary rocks of the Bahia basin, with the sandstones along the Amazonas, and with the rocks forming reefs of both Cretaceous and Tertiary ages along the coast from Abrolhos to Maranhão. He appears to regard the reefs as narrow remnants of the Tertiary beds along the east coast of Brazil.

M. A. Vital de Oliveira. Roteiro da costa do Brasil do Rio Mossoró ao Rio de S. Francisco do Norte. Rio de Janeiro, 1864.

This work, as the title indicates, is intended for navigators, but it mentions several of the reefs of the coast. One is reported at Murihú, one at Guaçandú and one at Ceará-Merim. That at Natal is said to be uncovered at low tide, and to end at the Ponta do Morcego, a little more than half a league north of Pinto (p. 71–73). Mention is made of the reefs at "Pontal da Susana," Cunhaú, Traição, Mamanguápe, etc. No distinction, however, is made between the different kinds of reefs.

Penn, James. The South American Pilot. Part I. East coast of South America, from Cape St. Roque to Cape Virgins. 4th ed. London, 1893.

In speaking of the reefs of the northeast coast of Brazil in general this writer says (p. 48): "The Recife, a singular ridge of coral rock, borders the coast generally at the distance of one-half to three miles, but in some parts much farther off, and extends more or less from the northeast point of Brazil, as far as Bahia; traces of it may be found more to the southward, and also along the north coast to Maranham. The reef, which is about 16 feet in breadth at the top, slopes off to seaward. . . ." In other parts of this work, no distinction is made between the stone and the coral reefs, and the assumption seems to be that they are all coral, though several of the most important stone reefs are mentioned, such as those at Rio Grande do Norte, Traição, Mamanguápe, Cunhahu, Pernambuco, and Santo Agostinho.

Antonio Bernadino Pereira do Lago. Memoria sobre a forte do mar em Pernambuco. Published in the Revista do Instituto Historico e Geographico do Brazil, 1862, p. 589–596.

This article is without date; it was written after 1814, however. The author says the reef (a bank of rock) extends from S. lat. 6° to 18°; that is, from Rio Grande do Norte to the Abrolhos almost parallel with the coast, in some places uncovered, in others concealed, here nearer the land and there further from it, and containing breaks or passages.

Filippe Francisco Pereira. Roteiro da costa do Norte do Brazil. Pernambuco, 1877.

This work, written for the use of coast pilots and sailing masters, speaks incidentally of many of the reefs of northern Brazil. Opposite page 36 is a map of the Barra de Goianna, Pernambuco, showing the position of a reef somewhat broken and curved.

He says (p. 43) there are reefs about the mouth of Rio Guajú, on the line between Parahyba and Rio Grande do Norte. The Barra do Cunhahú, Rio Grande do Norte, is also circled by reefs lying near the shore (p. 45). Others are mentioned (p. 50) at the mouth of Rio Ceará-Merim. Off Cape St. Roque he says the reefs are about 6 miles out and parallel with the coast, and extend 27 miles N.N.W. to Olhos d'Agua. These last are probably coral reefs, however.

Piso, Gulielmus. De Indiæ Utriusque Re Naturali et Medica. Amsterdam, 1658.

Piso lived at Pernambuco during the Dutch occupancy under Maurice of Nassau, 1637–1644.

Speaking of Pernambuco, this author says that the tide "strikes with great violence against a reef or bank called by the Portuguese *Reciffo*. All who have seen this reef are obliged to confess that it was placed there by a great kindness of nature. The ledge of rock, extending a long distance, opposes itself like a wall to the violence of the surf and mad elements, and gives ships safe stations and ports. It also supplies most abundant materials for buildings, and for the churches and monasteries which are the pride of Olinda and Parahyba. This same reef, sometimes broken and crooked, again continuous and straight, protects the greatest part of Brazil. (*Maximam Brasiliæ partem eadem nunc interrupto & flexuoso, nunc continuato rectoque dictu tuetur.*) Its breadth (it is very flat, and as smooth as if artificially polished) is twenty, sometimes thirty paces and more. Its height is such that it is rarely covered by the highest tide" (p. 6–7).

I have given this quotation at length, partly because it has been supposed that Piso is the original authority for the occasional statement that the reefs of Brazil are continuous.

The same description is quoted on pages 584–585 of Caspar Barlaeus's Rerum per Octennium in Brasilia. 2d ed. Clivis, 1660.

In Piso's *Medicina Brasiliense*, published in 1648 (pp. 3–4), the same account is given of the reef.

Porto Seguro, Visconde de. (Francisco Adolpho de Varnhagem.) Historia geral do Brazil, antes de sua separação e independencia de Portugal. 2a edição. Rio de Janeiro, n. d. Vol. I.

This work has a steel engraving (facing p. 352) showing the northern end of the reef at Pernambuco in 1630. Another (op. p. 504) has a view upon the reef looking north from near its southern end. (This picture is reduced and changed from one given in "*Die Unbekante Neue Welt*" of Arnoldus Montanus, p. 542, credited to Dr. O. D. (see Montanus above) and made during the Dutch occupancy, probably by Post.) Another plate (op. p. 530) gives a plan of the reef south of Cape Santo Agostinho, made in 1636. The map of the same reef given herewith, and made in 1899, shows that there has been no perceptible change in that great reef since 1636.

Porto Seguro, Visconde de. Nota acerca de como não foi na Corôa Vermelha na Enseada de Santa Cruz que Cabral primeiro desembarcou. . . . Acompanhada do texto integro da carta-chronica . . . de Pero Vaz de Caminha. Revista do Instituto Historico do Brazil, 1877, XL., pt. II., p. 5–37.

"Rio Buranhem, before entering the ocean at about lat. 16° 25′ S. meets a reef which runs parallel to the coast, nearly north-south, like that at Pernambuco. . . . This reef is well above low tide, in some places it has mangue bushes on it and in others sandy beaches" (p. 5).

Purchas. Purchas his pilgrimes, in five bookes. London, 1625. Vol. IV. Chap. 7, § 5, p. 1238.

"This place ('Arecias') is a league from Fernambuquo, being the harbour where all the Shipping that goes from Fernambuquo doe arriue; from this place to the Cape you shall see the Clifts as it were a wall made by Bricklayers, no higher in one place than in another, but all euen."

It is also stated that these "clifts," that is, the reefs, "lye along the coast as farre as the Riuer Saint Francis."

Rathbun, Richard. A list of the Brazilian echinoderms, with notes on their distribution, etc. Transactions of the Connecticut Academy of Arts and Sciences, 1879, V., p. 139–158.

The echinoderms listed in this paper are partly from the stone reefs of Rio Formoso and Pernambuco.

Rathbun, Richard. Brazilian corals and coral reefs. American Naturalist, 1879, XIII., p. 539–551.

In this article Mr. Rathbun remarks that the stone and coral reefs of Brazil are nearly coexistive, "but while the stone reefs are always confined to the immediate neighborhood of the shore, coral reefs frequently lie some distance out, at times forty or fifty miles."

Rathbun, Richard. Notes on the coral reefs of the island of Itaparica, Bahia, and of Parahyba do Norte. Proc. Boston Soc. Nat. Hist., 1878, XX., p. 39–41.

Notes on the characters of the coral reefs at the places mentioned.

Rathbun, Richard. Prof. Hartt on the Brazilian sandstone reefs. American Naturalist, June, 1879, XIII., p. 347–358. The author states that the paper "is partly in the very words of Prof. Hartt," but it is not always clear which parts Hartt is responsible for, or which are to be credited to Mr. Rathbun.

In any case this article is the most important one ever published upon the stone reefs of Brazil. It includes Hartt's own work done previously, and also most of the results of the work by the Commissão Geologica do Brazil on the reefs at Pernambuco, Porto Santo, Bahia, and Porto Seguro. In regard to the height of the reef at Pernambuco it is stated that it is about the same as high tide, "though on account of the great commotion made by the waves at such times, it is impossible to exactly determine this fact. . . . It is very evident that they [the reef rocks] are not the outcropping edges of beds of sandstone . . . but only narrow strips of stone of slight thickness formed in exactly the same position in which we see them to-day, that is, just below the level of high tide." This solidification is considered to be due to lime carried into the beach materials by percolating waters, both sea-water and rain, and by the "encroachment of the sea aided by rivers flowing behind them these consolidated beaches have often been separated from the main shore as distinct reefs; but sometimes this latter action has not taken place, and the hardened layer retains its normal position upon the beach." The dip of the beds is attributed to the false bedding of the beach sand as deposited and not to the upheaval of the coast. Of the Porto Santo reef on Itaparica at Bahia it is said that there must have been an elevation to raise the reef at that place so high above water.

Rathbun, Richard. A praia consolidada e sublivada e os sambaquis de Porto Santo. Archivos do Museu Nacional do Rio de Janeiro. 1878, III., p. 172–174.

Mr. Rathbun describes a stone reef at Porto Santo on the northeast corner of the island of Itaparica, which lies within the Bay of Bahia and northwest from that city.

He thinks it probably belongs to the same series of formations as the sand reef of Pernambuco, and "is the only example known of the elevation of such materials." This bank is three hundred metres long and rises four metres above the shore, falling away gradually both north and south. The lower three metres of this beach are consolidated, and on this rests a black sandy soil filled with shellfish and containing human remains. The bottom half of the beach is of corals and water-worn shells mixed with sand and small pebbles. In places it has enough lime in it to allow of its being burnt for lime. "This part of the beach resembles in structure and hardness the consolidated beaches east of the Bahia lighthouse. The hardening seems to have gone on more rapidly at some levels than at others." He regards the Porto Santo deposit as very superficial and recent; the shells and corals in it are all recent.

Reclus, Élisée. Nouvelle géographie universelle. La Terre et les hommes. Tom. XIX. Amérique du sud: l'Amazonie et la Plata etc. Paris, 1894, p. 222–223; 244.

He says there is a line of reefs extending from the mouth of the Parahyba to that of Rio São Francisco, some of them of coral and others, like that of Pernambuco, of a different origin. "There is probably not in the world a formation that has more the appearance of having been built by the hand of man." It is stated to have a width of from thirty to sixty metres, to be flat on top, and uncovered at low tide. The rock is said to be of a compact sandstone "in which it is difficult to distinguish the bedding." He thinks the material was probably a line of dunes, hardened by time.

He states that Agassiz thought the reef was a terminal moraine, but makes no reference to the publication of this opinion.

Opposite p. 480 is a fine wood engraving of the Pernambuco reef, the view being taken from the lighthouse at its northern end; and on p. 245 is a map of Pernambuco showing part of the reef.

Rolt. A new and accurate history of South-America. . . . By Mr. Rolt. London, 1756, p. 546.

"The port of *Arracife*, opposite the town of *Pernambuco*, is so called from its situation among a ridge of rocks, or sands; and the harbor of *Pernambuco*, or rather *Infernoboco*, the mouth of hell, was so named by the *Portuguese*, on account of the rocks and shoals, under water, at its entrance." A similar explanation of "Pernambuck" is offered by Arnoldus Montanus in his Unbekante Neue Welt, p. 434. It should be noted that this explanation of the word Pernambuco is not correct.

The original Tupi name appears to have been *Paranã-buc*, meaning *the sea breaks,* referring to the surf breaking on the reef. See *O Tupi na geographia nacional.* Por Theodoro Sampaio, p. 52 and 146. S. Paulo, 1901.

Roussin, Le Baron. Le pilote du Brésil, ou description des côtes de l'Amérique Méridionale. Paris, 1827.

Speaking of the coast between Sta. Catherina and Maranhão (p. 34), Roussin says it is skirted its whole length, except at certain intervals, by two lines of shoals (enveloppée de deux ceintures de hauts-fonds). The inner one of these fringes the shore with its rocks, especially from Cape Frio to Maranhão, "often at sea level, sometimes rising above it from one to ten feet, more commonly submerged." He states that by breaks in this reef almost all the ports of the coast are formed. A partial list of those believed to be so formed is given (p. 34). The theory advanced by this writer to explain the reefs is that they are due "in part to the heavy surf." He conceived that the waves charged with the debris of the shore were thrown back upon themselves (p. 35); "but this movement of repulsion cannot fail to be counteracted by the contrary pressure of the ocean mass; and there must result a sort of stagnation of the waters at a certain distance from the coast and the materials brought away must be deposited at this point of repose." He adds in a footnote that this explanation does not apply to the uncovered rocks, but to the shoals connecting them.

He mentions several of the stone reefs of the coast, but gives no specific information except such as might be useful to sailing masters.

Saint-Adolphe, J. C. R. Milliet de. Diccionario geographico historico e descriptivo do Imperio do Brazil. . . . Por J. C. R. Milliet de Saint-Adolphe e transladada, . . . pelo Dr. Caetano Lopes de Moura. Tomo II. Paris, 1845, p. 292.

"All of Brazil, like the province" (of Pernambuco), "is protected from the waves of the sea by a natural wall of reefs broken here and there to give passage to the streams, from the city of Bahia to the ponta de Touros in the province of Rio Grande do Norte." This writer mentions several reefs in front of certain ports along the coast, but there is nothing to show the nature of them.

Serres, Marcel de. Sur les coquilles pétrifiées des environs de Bahia. Compt. Rend. 1854, XXXVII., p. 362–363.

A short note referring to the views of Spix and Martius upon the Bahia reef sandstone. He thinks that those authors overlooked the fact that the shells in the Bahia rocks show that their petrifaction has taken place in our own day.

Serres, Marcel de. Note sur la pétrification des coquilles dans l'océan actual. Compt. Rend. 1853, XXXVI., p. 14–16.

The author gives the results of the observations of M. Christine, a surgeon in the French navy, at Bahia. He speaks of the recent sandstones near the lighthouse and north of it. He says they are very hard, are used for building in Bahia, that they contain many shells, and also petrified shells, living species, without traces of animal matter, but with colors fresh. He is of the opinion that these examples show that shell-bearing sandstones are in process of formation in the present seas, and still more extensively in the oceans; that petrification goes on at present; "that the shell-bearing sandstones of Bahia must have been deposited after the petrification of the shells which they enclose."

Serres, Marcel de. Sur le dépôts récents des côtes du Brésil. Compt. Rend. 1860, L., p. 907.

This brief paper (a letter to Élie de Beaumont) was called forth by the letter of M. Liais upon the Pernambuco reef. M. Serres finds in that letter fresh evidence in support of petrification going on at the present time.

Smith, H. H. Brazil, the Amazons and the coast. New York, 1879, p. 438–439.

"The reef looks much like an artificial breakwater from end to end, it forms almost a straight line, and the height is very uniform — about ten or twelve feet above high water." On p. 439 there is a wood engraving of the reef made from a photograph taken from the lighthouse at its north end.

Santa Teresa, Gio: Gioseppe di. Istoria delle guerre del regno del Brasile accadute tra la corona di Portogallo e la republica di Olanda. Roma, 1698.

In Part II., at pp. 202–203, are a view and a plan of Pernambuco, both exhibiting the reef. The plan is obviously inaccurate so far as the city of Recife is concerned, and the reef is represented as strongly curved. It is stated that (Part I. p. 21): "The Port of Recife is one of the most frequented of the world; it is protected by a wonderful mole formed there by nature, which rises above the water, and extending a great number of leagues, cut by nature with such regularity as if they were so many moles made artificially at great expense."

Souza, Pero Lopes de. Diario da Navegação da Armada que foi á Terra do Brazil em 1530 sob a Capitania — mor de Martim Affonso de Souza. Escripto por seu Irmão Pero Lopes de Souza. Lisbõa, 1839.

This writer was at Pernambuco in 1530, and makes mention of the reefs at that place, at Cabo Sto., Agostinho, and at São Miguel (p. 14–15). He gives no descriptions of them, however.

Souza, Gabriel Soares de. Tratado descriptivo do Brazil em 1587. (Published anonymously at Lisbon in 1825.) *Revista do Instituto Historica e geographico do Brazil*, 1851, XIV.

This is probably the oldest account we have of the Brazilian reefs. They are not described in much detail, however, and no distinction is made between stone and coral reefs. The author mentions (p. 25) reefs near Goaripari just south of Cape St. Roque. The port of Rio Grande, he says, has a reef like that at Pernambuco; reefs are mentioned at Aratipicaba (p. 26); others from Rio Magoape to Itamaracá (p. 27, 31). The Pernambuco reef is said to be two leagues long (p. 33); that at Rio Formoso is mentioned, also those at Rio Camaragipe, at Porto Novo, and at Curruripe (p. 37). There is said to be a reef at the mouth of Vasabarris, at Braz Affonso, at Rio Joanne, Rio Vermelho, and at Porto Seguro. He tells of the use (p. 354) of the reef rocks at Bahia for building the city, and says these rocks were covered at high tide; that "the rock is white and hard, and does not go to pieces, but is hard to work because it wears the tools. Fine and beautiful works and very large grave stones are made of it. To one examining it, it seems that this stone is made of sand hardened, for along these same reefs and close to them the rocks are all black, while the former is very white after it is cut. It is not very soft though, and when worked it shows a sandy grain, and often oyster and other shells are found inside the rock, and small pebbles. From this it is held that this rock is formed from sand, and that it has been hardened by the coldness of the sea-water, which is easy to believe, for there are found about these shores mud filled with sand and congealed and hard as rock, and some tree trunks also covered with this mass as hard as if they were of stone."

Spix. J. B. von, and **C. F. P. von Martius.** Reise in Brasilien. München, 1828, Vol. II., p. 795, 799.

On p. 795 it is said that "the harbor of Recife is formed by the rock reef which gave name to the place, and extends along and parallel to the coast in front of the town." On page 799 they have a brief note upon the coral reefs along the coast of Ceará.

Varnhagem. See **Porto Seguro, Visconde de.**

Wappæus, J. E. A geographia physica do Brazil. (Edição condensada.) Rio de Janeiro, 1884, p. 17–18.

From Cape St. Roque to Olinda, and even to Bahia, there is a narrow bank of coral which begins to appear at Ceará. In places this connects with the shore, at others it is three hundred to four hundred metres away or even still further. At some places the reef is broken, forming passages for vessels and even harbors, as at Pernambuco and Rio Grande do Norte.

Résumé of the Bibliography.

The following facts stand out prominently in this bibliography: —

I. Nearly all the descriptions of the Brazilian stone reefs hitherto published relate to the one at Pernambuco, due no doubt to the fact that Pernambuco is the most important port of Brazil north of Bahia.

II. The most valuable papers are those of Darwin, Hartt, Rathbun, Hawkshaw, Fournié, and Béringer.

III. Except in so far as they show that there has been no important changes in the reefs within historic times other writings have but little or no geologic value.

No attempt has been made to get together the old maps showing the reefs of this coast, for with very few exceptions these reefs are put down in a more or less conventional manner, without attempting to show their real forms or extent. The earliest of these maps are probably those made under Admiral Lichthart during the Dutch occupancy (1637–44). The original atlas of these beautiful charts is in possession of the *Instituto Archeologico e Geographico Pernambucano*, where the writer had the pleasure of examining and copying them. The same institution has several other maps of Pernambuco of even earlier date. The value of all these maps, however, is historical rather than scientific.

IX.

The Coral Reefs.

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When the work on the stone reefs was begun it was not intended to include with it anything upon the coral reefs. It was only after the work was nearing completion that it seemed advisable to utilize the notes made on the corals, and to use the geological history of the stone reefs as far as possible to throw light upon that of the coral reefs. For this reason these notes are fragmentary. I have endeavored, however, to bring together what others have written upon the coral reefs in order to make the paper as nearly a complete account of the coral reefs of Brazil as can be written with our present information.

The accompanying map shows the distribution of the coral reefs so far as it is known (Plate 1) at present.

LOCAL DETAILS.

The Rocas. — In 1852 the Rocas was visited and was first mapped and described as a coral island.[1] This island is eighty-four miles due west of the Peak of Fernando de Noronha, and one hundred and forty-four miles from the Brazilian mainland. Its centre is in south latitude

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[1] Report and charts of the cruise of the U. S. Brig "Dolphin" made under the direction of the Navy Department, by Lieutenant S. P. Lee. U. S. Navy, Washington, 1854 (33d Cong., Ex. doc. 59, p. 81–85).

3° 51′ 27″; longitude 33° 48′ 57″ west of Greenwich. "The reef extends about one and one-fourth miles in latitude and nearly one and three-fourths miles in longitude and is covered at high water with the exception of Sand and Grass islands on the west and the scattered rocks on the south and east sides. These objects are from ten to fifteen feet above the reef, which is formed of coral, generally level, though with many holes in it. . . . We found coral bottom at fifteen fathoms, six miles east of the reef, but no bottom at thirty fathoms, two and one-half miles north-northeast, nor at seventy fathoms four miles southwest of it. The tide rises about five feet." (See page 82 of that work.)

Certain points are marked on Lieutenant Lee's chart as black rocks amid the coral reefs, suggesting that the reef may rest upon a base of eruptive rocks.[1] Findlay[2] has the following: "The Rocas. This low coral reef is perhaps the most formidable danger in the Atlantic. It is the only one of its character in that ocean — a true atoll isolated from all the surrounding lands, so many of which are found in the Pacific."

This author quotes as follows from a report of a visit by Commander Parish made in 1856. He "obtained coral bottom in thirteen fathoms," before the island was sighted, and again he "anchored in twenty fathoms," before the island was sighted, and again he "anchored in twenty fathoms, coral bottom, at about two and one-half miles from the shore."

In 1857, Captain J. H. Selwyn, R. N., resurveyed the Rocas and wrote of it then: "It is a perfect coral island, circular, about two miles in diameter, and has in its centre a shallow lake with an opening to the sea. The greater part of the reef is under water. There are two sand banks, one on the southwest side, and the other on the northwest side of the island. These are ten or twelve feet above water at all tides, and are two hundred or three hundred yards long. The smaller has on it some stunted vegetation and hazel trees." Reclus speaks of the Rocas as a "veritable atoll of coral like those of the Indian Ocean, enclosing a lagoon about ten kilometres in circumference."[3]

There is also a valuable article upon the Rocas published anonymously in the "Mercantile Marine Magazine."[4]

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[1] Dr. J. B. Regueira Costa, of Pernambuco, has kindly obtained for me specimens of the black rocks of Rocas, but up to the time this report goes to press they have not been received.

[2] Findlay, Alexander George. A sailing directory for the Ethiopic or South Atlantic Ocean. 9th ed. London, 1883, p. 227–231.

[3] É. Reclus. Nouvelle géographie universelle. XIX. Amérique du Sud, p. 223. Paris, 1894.

[4] Mercantile Marine Magazine, XIII., p. 33–50; 65–80; 141–143. London, 1866.

Cape St. Roque reefs. — It is greatly regretted that I have not been able to visit the reefs off Cape São Roque, for without doubt they are quite as important and as interesting as any on the Brazilian coast.

These São Roque reefs are upon a part of the coast never visited by large steamers. Coasting steamers from Pernambuco and Parahyba touch at Natal, thirty-six kilometres from the southern end of the Maracajahu reef, and this is as near as one can get to them by such conveyance. At the time of my visit to Natal, coast of Rio Grande do Norte, in June and July, 1899, it was impossible for a sailing vessel to pass the reefs and then return southward. Once past the Cape it would be necessary to remain there for months for the winds to change in order to get back to Pernambuco. For this reason when I reached Natal I turned back southward in order to see the coast south of Recife.

Our knowledge of the Cape São Roque reefs is so scanty that it cannot be said positively that they are of coral. It is true that Findlay and Penn both speak of them as being coral, but these authors do not always discriminate between coral reefs and reefs of other kinds. So far as can be learned they have never been visited by a naturalist.

The entire group extends from Cape Calcanhar on the north nearly to Cape St. Roque, a total length of about forty-two kilometres. There are three groups of reefs: the northwestern, called the Sioba reefs, the middle group, called Fogo, and the southeastern group known as the Maracajahú reef. Between these reefs and the mainland is the St. Roque channel, with a depth of from three and a quarter to three and a half fathoms. These are therefore barrier reefs.

Lavandeira reefs. — About sixty kilometres west of the Sioba reefs of the São Roque group, on longitude 36° W. of Greenwich, is a large reef known as the Lavandeira, with several smaller ones both east and west of it. These reefs are off the point of land known as Tres Irmãos. I have not examined them, but they are probably of coral.

João da Cunha reef — probably of coral — is about thirty-five kilometres northeast of the mouth of Rio Mossoró, W. lat. 37°. It seems to be only a small isolated reef.

Ceará reefs. — Of the coral reefs along the coast of Ceará, Spix and Martius say: "On the sea-coast the numerous corals are used for making lime. . . . These banks are the same as the coral reefs further south along the coast of Pernambuco, Parahyba, and Rio Grande do Norte, and are covered here and there with thick beds of shellfish. The corals sent by Mr. Sampaio from the vicinity of Cidade do Forte belong to the genus *Nullipora*."[1]

At a number of places along the coast of Rio Grande do Norte the reefs are neither coral nor of the ordinary recent sandstone, but are of the more resisting iron cemented sandstones of the Cretaceous or Tertiary series. These beds, as has been pointed out in the geological introduction, are often formed at the bases of the bluffs, where, when the overlying beds are removed, they are in the right position to leave reefs close to mean tide level. Such are the reefs off the Pittinguí, Cape Branco, Jacumã, etc. Even if the São Roque reefs are all of coral, the chances are that they are built upon some such base as the one here mentioned.

The absence of coral reefs along the entire coast from Natal, south latitude 5° 45′, to the mouth of the Rio Parahyba do Norte, south latitude 6° 57′, is striking. All the reefs within this space are either sandstone reefs or hard Cretaceous or Tertiary beds rising to about mean tide level.

Fernando de Noronha. — The following notes upon the corals of the Fernando de Noronha archipelago were made during a three months' visit to that island in 1876, when the writer was a member of the Geological Commission of Brazil. They are given here, not on account of their importance, but partly because mention has been made by Mr. H. N. Ridley of the "coral reefs" about the group,[2] and partly because one might naturally expect to find coral reefs about that group of islands.

The main island of Fernando is volcanic, and all the outliers around it are of similar origin except Ilha do Meio and Ilha Raza, which are of aeolian sandstone.[3] Properly speaking there are no coral reefs around Fernando, though growing upon the rocks about the group are a few corals, and still other corals that were not found in place are from time to time torn up from the ocean bottom and thrown upon the beaches by the heavy surf. The following is a list of all the species collected on and about the island. For the identifications I am indebted to Mr. Richard Rathbun, formerly of the Geological Commission of Brazil, now of the Smithsonian Institution.

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[1] J. B. von Spix u. C. F. P. von Martius. Reise in Brasilien, II., p. 799. München, 1828.

[2] Journ. Linn. Soc. Zoology, 1890, XX., p. 559.

[3] J. C. Branner. The aeolian sandstones of Fernando de Noronha. Amer. Journ. Sci., 1890, XXXIX., p. 247–257.

Corals from Fernando de Noronha, Brazil.

Collected by J. C. Branner.

1. *Gorgonia quercifolia* Milne Edwards and Haime.
2. *Gorgonia* . . . sp. (?).
3. *Siderastraea stellata* Verrill.
4. *Favia conferta* Verrill.
5. *Mussa* sp. related to *Mussa verrillii* Rathbun.
6. *Millepora brasiliensis* Verrill.

To this list Mr. Ridley's collecting has added

7. *Astrangia solitaria* Lesueur.
8. *Favia ananas* Lamk.
9. *Favia deformata* M. Edw. and H.

Professor P. Martin Duncan, who identified Mr. Ridley's material, remarks that "this little coral fauna has the Abrolhos Reef homotaxis."[1]

Mr. Rathbun tells me that the species from Fernando are slightly different from those of the coast reefs.

The *Gorgonia quercifolia* is washed on shore at the time of the high tides, or after very rough water. The specimens are found principally in the Bahia do Sudoest and upon the point of the island east of Santo Antonio. Some of the specimens are three feet in length. They are generally more or less bruised by the surf. I was unable after much hunting to find these corals growing in place. The fishermen insist that they do not grow near the island, that they are torn up from the deep sea and brought to the land by the waves. The continued roughness of the water and the lack of proper boats upon the island make searching for these corals very unsatisfactory work. I believe the *Gorgonias* grow in or near the mouth of the Bahia do Sudoest, but the small jangadas of Fernando could not live in that troubled sea.

The *Gorgonia* . . . sp. (?) is very large and different from anything yet found on the Brazilian coast. But few specimens of this species were found. It closely resembles a species figured by Milne Edwards in his *Histoire Naturelle des Coralliaires* on Plate B. 2, fig. 6, as *Cricogorgia ramea*, but which is unmentioned in the text.

The *Mussa*, referred to *M. Verrillii* of Rathbun, can hardly be said to be rare, though I found but one living specimen on the whole coast. This was found growing in a tide-pool at the base of Morro dos Remedios.

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[1] Journ. Linn. Soc. Zoology, 1890, XX., p. 570.

Others were found washed upon the beaches, but much broken and worn. The millepores are uncommon, and the specimens obtained are poor and generally worn. None of the corals growing about the shores of Fernando are abundant, and the specimens are very poor as compared with those growing along the Pernambuco and Alagôas coast reefs.

There are certain calcareous growths about the shores of Fernando de Noronha that are worthy of mention. These are formed by Serpulae, corallines, and other lime-secreting organisms growing upon volcanic rocks in place, and building up stony, calcareous rings that enclose terraced basins of various sizes.

The accompanying sketch is of one of the large nests of diminutive basins to the east of Morro Francez. In general appearance these basins resemble the travertine deposits of Gardner's River in the Yellowstone National Park. The pools are full of animal life, and the water is constantly renewed by the waves breaking over the rocks.

Similar deposits about a mile long grow upon the rocks along the southern coast of the island in front

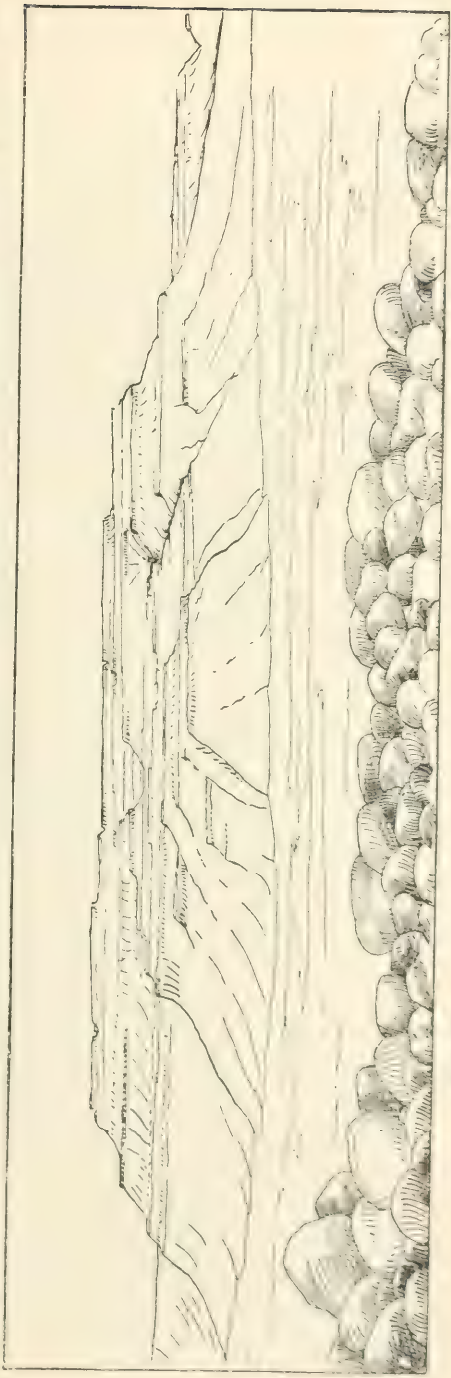

Fig. 96. Calcareous terraces, north side of the island of Fernando de Noronha.

of the Viração. They were not seen, however, on the northern side of the island.

Mr. Agassiz has described similar forms on the Bermudas as serpuline atolls. He observes, however, that they are also of Algae, corallines, and of barnacles, and other invertebrates.[1]

The coral reef of Parahyba do Norte.[2] — It used to be thought that the reef of Pernambuco was a part of one almost unbroken system of reefs extending along the whole coast of Brazil. There was for a long while more or less difference of opinion as to whether these reefs were of sandstone or of coral. As a matter of fact the Pernambuco reef is of stone, and although stone reefs do occur at other places along the coast, many of the reefs that were formerly supposed to be similar to that at Pernambuco, and a continuation of it, have been found to be of coral. Among these is the one at Parahyba do Norte, which was examined by the writer while a member of the Commissão Geologica do Brazil. The form of the Parahyba coral reef and the configuration of the coast and of the land behind lead to the belief that this coral reef is built upon and now conceals a reef of sandstone like those of Pernambuco and Mamanguape, only somewhat lower than the latter ones. It is worthy of note that the Parahyba reef lies across the mouth of an old embayment or estuary that has silted up and built out the long flat peninsula of Ponta da Matta. Corals could not have lived where the reef now stands until after the peninsula was formed and after there was a solid bottom to which the polyps could become attached.

The lighthouse at the mouth of the Rio Parahyba do Norte stands on the outer or seaward edge of the northernmost end of the Parahyba reef; from this point the reef bears almost due south, keeping approximately parallel with the shore and on an average of 1100 metres distant from it. Lying between the reef and the river (Rio Parahyba do Norte) is a narrow neck of land, on the northern point of which is a little village known as Ponta da Matta.

The reef is approximately straight, with the irregular zigzag outer face so common on coral reefs. It has a total length from the lighthouse to the Barreta do Poço of nearly seven kilometres, and, with the exception of two narrow passes, or barretas, barely wide enough for jangadas two metres in width to pass, it is unbroken.

The reef varies considerably in width, but everywhere it is higher on the seaward side, and slopes gradually from its outer or eastern margin inward toward the channel. The channel on the landward side of the reef is a shallow one, being only two metres deep at low tide toward the upper end; there are also a few deeper pools behind the reef near its lower end. The reef at its northern end, near the lighthouse, is low — only a few points being a foot out of water at the lowest tide. At the northern end the top of the landward side of the reef is comparatively smooth, while the outer or seaward side is exceedingly rough and difficult to walk over. The points of the calcareous growths are too sharp to be stepped upon, and too weak to sustain a man's weight, so that when one tries to walk over them he breaks through and sinks to his ankles or to his knees, and gets his legs and feet twisted and bruised. There are no large corals on the northern part of the reef; the only genus common is *Porites*, and of this the specimens are small and insignificant. The higher parts of the rocks are overgrown by brown polyps which grow in large patches, and by green, grape-like clusters of seaweeds. These polyps and seaweeds are found the whole length of the reef. Following the reef toward the south, its landward side has the bottom in places covered with sea-urchins, in others with seaweeds or with sand. Here or there the inner or land side of the reef has a few *Milleporae*, *Porites*, and *Favia*, though the specimens are all small. Along the inside near the Barreta do Leitão in the shallow water is a great number of small red starfishes, of which specimens were collected. Large quantities of the small, yellow, branching coral, *Eunicea sulphurea*, grows upon the inside of the reef along its entire length. It is especially abundant near the Barreta do Leitão, where there are also many fine specimens of *Plexaurella*. The chief collections made on this part of the reef were of the corals first mentioned, starfishes, small crabs, and a few gasteropods. Near the Barreta da Onça the reef is higher, and its surface much harder than it is near the lighthouse. Below the Barreta da Onça the surface of the reef is covered with reddish-brown sand, and this continues to nearly opposite the southern extremity of this section of the reef. At the lower end of this section of the reef the sand is about one metre deep. The barrier — the reef with its covering of sand — continues to increase in height as the south end is approached, the highest parts projecting nearly or quite one metre and a third above the water at extreme low tide. On the outer part of the rocks are many Bryozoa and nullipores, but, owing to the ragged surface and the breakers that dash upon it, collecting them is difficult and dangerous even in a sea more than ordinarily calm. The shell of calcareous matter formed by lime-secreting animals of different kinds is here harder than it is near the upper end of the reef, though one may sometimes break through and sink to his armpits, or even over his head without touching bottom. It is here that the course of the barrier is more broken into zigzags.

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[1] Bull. Mus. Comp. Zoöl., XXV. No. 2, p. 253–272, Plates XXII.–XXVI.

[2] The observations on the Parahyba reef were made in 1875; a trip to Parahyba in 1899 added nothing of importance to the earlier notes.

The Barreta da Onça, about the middle of the reef, is ten or fifteen metres in width, and allows the heavy swell from the ocean to pass through. This entrance is deep, and along its bottom grow several large *Millepores*, which could not be collected on account of the depth and roughness of the water. Near the south end, and on the inside of the reef, there are a few pools containing a number of corals of different kinds. No *Mussas* were found on any part of the Parahyba reef. With the exception of the absence of *Mussa harttii* and the presence of *Eunicea sulphurea*, the fauna of this reef seems to be about the same as that of Maria Farinha on the Pernambuco coast. The marked absence of living corals from the northern part of the reef is probably due to some extent to the fact that they have been and still are taken out by the inhabitants living in the neighboring villages for the purpose of making lime. This burning of the corals for lime must be a very old custom, and the amount of coral rock thus used must have been at times very great. The Fortaleza da Barra at the mouth of the river, built in 1712 on the Ponta da Balea, has pieces of imperfectly calcined coral in the mortar, and it is plastered in places with lime made from the corals of this convenient reef. The city of Parahyba gets its supply of lime from the same source, and the burning is still carried on. The result is that there are no large coral heads to be found much short of the southern extremity of the reef. Here, however, are some very rich pools a hundred metres or so within the barrier edge of the reef filled with *Eunicea*, *Porites*, *Favia*, *Plexaurella*, and *Millepora*. The part of reef facing the waves of the open sea also abounds in corallines, seaweeds, crustaceans, etc., and the cavernous calcareous pieces below look like fairy grottos as the retreating waves leave the Bryozoa and delicate Algae dripping with water. The channel between the coral reef and the land admits of barcaças, which may pass in and out at the Barreta do Poço. At low tide, however, only the smallest barcaças can pass readily. At this last-mentioned barreta the end of the northern reef lies outside of the northern end of the reef to the south, and the ocean current brings in through this little opening large quantities of seaweed which pile up on the south side of one or two of the *curaes*[1] nearest the barreta. At one of these the weed was piled up at the time of my visit to the depth of more than a metre, and lay heaped along the shore for more than a hundred metres. These piles of Algae are found only in this one place about the Parahyba reef and always on the south side of the obstacles.

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[1] Cural is the name given the fish-traps made of poles driven into the mud or sand at the bottom of the water. The plural is *curaes*.

The coral fauna of the Parahyba reef is not so rich as that of the Maria Farinha, and of Rio Formoso reefs farther south. The living corals are scarce, possibly on account of their being used for lime-making, and the continual disturbance of the heads and prominences of calcareous formations by the lime-burners must affect the life of the reef perceptibly.

Coral reefs between Parahyba and Recife. South of the Parahyba reef there are no considerable coral reefs again until the Barra de Goyanna is reached. The reef-like breakers near the shore at Tambába and just south of Jacumã are of Tertiary rocks — those at the latter place are fossiliferous. South of Tambába it is possible that there are some small low patchy coral reefs extending to a little south of Petimbú. These reefs are only uncovered, however, at the lowest tides, and could not be examined at the time of the writer's visit.

The reefs put down on the hydrographic chart as Les Tacis and said to be uncovered at quarter ebb, I was unable to find. North of the Barra de Goyanna is a sandstone reef uncovered at quarter ebb, but it is known here as the Pedra do Galé, and has neither the great length nor the position given the reef called Les Tacis on the chart. South of the Barra do Goyanna the sandstone reef is continued in a southwesterly direction. Outside of and overlapping its south end is a long, patchy line of coral reefs extending to the Barra do Gerimum. The reefs are interrupted at the Barra de Catuáma, but they begin again east of the northern end of the Island of Itamaracá and continue a little more than half the length of that island. The reef is nearly three kilometres out from the east shore of the island. The corals grow also on the inside of the Itamaracá reef nearly to the shore. At the lowest tides the coral banks are exposed at many places between the main outer reef and the island. The rock is taken out and is used extensively both for building-stone and for lime-burning. In the heaps found on the shores, especially at the town of Itamaracá, the most common form is *Porites.* Some of the heads of this genus measure 47 centimetres in length. Millepores are also common. In the shallow water opposite the church the *Porites* is especially abundant. The *Porites* is known here, as it is at many other places along the coast, as "cabeça de carneiro" or sheep's head.

The dredge brought up very calcareous sands from the shallow waters between the Itamaracá reefs and the island.

South of the island of Itamaracá there are two reefs, — one on either side of the Barra de Maria Farinha. The one between this channel and the land I saw many years ago, and my recollection of it is that it is a stone reef. I cannot speak positively, however, as the notes then taken are not now in my possession, and at the time of my last visit the water was too high to permit a re-examination. The reef east of the Barra de Maria Farinha is of coral. It has a length of nearly four kilometres. The Maria Farinha reef is separated from one just south of it by the Barra de São José. This last reef has a length of five kilometres, its southern end being near the shore at the old fort Pau Amarello. The Barra do Pau Amarello separates this reef from another shorter coral reef that runs as far south as Quadras.

These three reefs, Maria Farinha, Pau Amarello, and Quadras, overlap each other somewhat, their northern ends all lying east of the reefs just north of them. They are from one to two kilometres out from the beach.

The near-shore reef south of the mouth of Rio Doce is of sandstone, and is described on page 59 of this report.

Off the lighthouse at Olinda are some reefs uncovered at the lowest tides, but they are small and ragged. I have not been on them. They are generally supposed to be of coral, but the existence on shore of the Tertiary rocks leads me to suspect that they may be the hard parts of sedimentary rocks.

The coral reefs from Pernambuco to Santo Aleixo. — At and south of Pernambuco the reefs are of sandstone as far as Boa Viagem. No coral reef is visible outside of the sandstone reef along this distance, but about Boa Viagem the sands of the beach are very calcareous.

The first considerable coral reef south of Pernambuco is at Candeias. At the point of land near Candeias church the coral reef is one kilometre off shore. Its northern end is opposite Venda Grande, and its southern end is nearly opposite the Barra das Jangadas, giving it a length of nearly three kilometres. Corals grow abundantly on the landward side of the reef, especially through the openings or breaks in it.

The collection of corals made by the *Commissão Geologica do Brazil* in 1875 and afterwards deposited in the Museu Nacional at Rio de Janeiro was made partly on the Candeias reef.

At the Pedras Pretas north of Cape Santo Agostinho there are many patches of coral reefs growing upon the trachyte that forms most of the beach at that place. The patches of coral extend north of the trachyte exposures for 300 metres. These fragmentary reefs at Pedras Pretas are all dead so far as the corals are concerned, and are now covered with worm tubes.

The next coral reef south of Pedras Pretas is at Cupe, ten kilometres south of Cape Santo Agostinho. It is only a short and broken one, is 600 metres out from the beach with which it is parallel, and lies due east of the sand point at that village.

At Porto de Gallinhas, south latitude 8° 28′ 30″, is another coral reef, about four kilometres long. On the beach opposite the reef are calcareous sands hardened into a soft sandstone. At one place — the large storehouse on the beach — this rock is hard and very like the fossiliferous rock of the stone reefs, but further down the coast it is not so hard, and is more calcareous. These beach rocks have a seaward dip that would, if continued, carry them beneath the coral reefs; from this it is inferred that the landward portions of the coral reefs are newer than the sandstones.

There is another coral reef just south of this one, at Maracahýpe. It lies across the mouth of Rio Maracahýpe, across Serrambý point and passes on to the south, ending west of the Island of Santo Aleixo. Its total length is about nine kilometres. There are many small breaks in it within this distance. The most abundant species of the corals is *Porites*, heads of which, with other coral rocks, are gathered here for the manufacture of lime.

Santo Aleixo. — The island of Santo Aleixo, also known on the hydrographic charts as Navigators' Island and Donally's Island, is opposite the Barra de Serinhaem, and about two and a half kilometres from the shore. The island is of eruptive origin and the rock composing it is a grayish-green quartz porphyry. It is 883 metres long, its greatest length being from north to south. On the southeast corner is a little hill 23 metres in height, and on the southwest corner is another smaller and lower hill.

There is a quarry in the igneous rocks on the south side of the island, and east of the quarry are patches of a calcareous fringing reef, which is narrow near the quarry, but it widens to about 40 metres. From this point to the southeast extremity of the island the outer margin of this fringing reef makes nearly a straight line, though the land curves in to the distance of nearly three hundred metres, forming a sort of shallow bay. The reef ends at the southeastern point of the island. It is low, not rising more than a metre out of the water at low tide, and presenting the general features of other calcareous reefs, being by turns hard and flat, cavernous, shelly and fragile, and filled with pools of water containing seaweeds and a few small corals. The part nearer the igneous rocks is the more solid; further from the shore it becomes more cavernous, the most fragile places being where the reef has its greatest width. It is highest along the outside, where it is covered by the dark and brownish polyps, seaweeds, and other calcareous growths. The pools in this reef have in them a few small corals, *Siderastraea* and *Favia*, the specimens of the latter genus being the finest I have seen on the Brazilian coast. The specimens of *Siderastraea* are small, none being found larger than a man's head. It is probable that many of the corals have been removed from this reef for the purpose of making lime.

To the oceanward of the southeastern corner of the island where the fringing reef ends, the rocks are rough and are washed high up by the waves, which break here with full force. Wherever the water breaks over the top of one of the high rocks at this corner of the island and runs down the inside surface, this inside is covered by calcareous terraced rings which grow along the sides and over the surface parallel to each other like broken contour lines. These rings contain little pools of water one above another, and this water is continually renewed by the splashing of the waves and by spray from the ocean. These little bands are about three centimetres in thickness, are from eight to thirteen centimetres high, and are surmounted by rows of barnacles.

The outer side of the rocks along the northeast part of the island appears to be crusted over by dark-brown corallines. Near the middle of the east side of the island there is a large pool among the higher rocks of the shore, the water of which is continually renewed by the waves; this pool contains a few fish, corals, etc. — all quite beyond tide level. It is only by leaping that the waves reach this height, but the island standing so well out at sea receives the full force of the waves, and they are thrown by the huge blocks of rock at the base of the bluff high into the air, and are thus carried as spray or as waves high up the sides of the rugged cliff.

Near this large pool and supplied in the same way are two other pools, one a little above and emptying into the other. The two are about the same size, being about twelve metres in length by one to two metres in width, and a metre or more in depth. These higher pools contain excellent exhibitions of the wearing or dissolving power of the sea-urchins upon rocks. The sides of the rocks are almost completely covered with the holes made by these animals. Hard as this igneous rock is they have succeeded in boring holes in some places to the depth of nearly five centimetres. This sea-urchin is *Echinometra subangularis* (Leske) Desme — the same species as that found upon the stone reefs at the city of Pernambuco.

On the north side of the island, where the waves are not so violent, a calcareous reef is forming among the eruptive rocks.

The coral reefs between Santo Aleixo and Maceio. There are several small reefs south of Santo Aleixo and north of Rio Formoso. Of these the largest are one lying off Gamella, and another a little to the north and to the landward of it.

At Rio Formoso the sandstone reef lies across the mouth of the river, and corals grow over the seaward side of the sandstone. Nearest the stone reef the corals occur in irregular patches, but further out they form two well-defined reefs. The positions of these reefs are shown on the map of Rio Formoso, Figure 51, p. 83.

The channel between the corals growing on the outer face of the stone reef and the coral reef to the seaward of this has it perpendicular sides covered with fine specimens of living corals. The genus *Mussa* is especially abundant and fine. The bottom where not covered with fine mud has growing over it fine specimens of Millepores, which are popularly known hereabout as *itapitángas.*

It was on this inner coral reef that many of the finest specimens belonging to the Commissão Geologica do Brazil were collected by the writer in 1875. Upon the extinction of the Commissão this collection was turned over to the Museu Nacional in Rio de Janeiro. The corals from these reefs have long been burned for lime, and the most accessible of the large heads have been removed by the lime-burners.

The outer Rio Formoso reefs cross the sandy Manguinho Point south of the river and continue as parallel reefs halfway across the bay north of Tamandaré.

Off the point north of Tamandaré (see p. 161 for chart) the coral reefs begin again as broad double reefs, and cross the mouth of Tamandaré Bay, leaving one considerable break at the bar, and continuing south of it as a single reef. This reef stands well out of water at low tide. Tamandaré would probably be an excellent place to study the reefs of this part of the coast. The town is large enough to offer facilities that cannot be found at all places, the bay is accessible to large vessels, and the extent of the reefs, their height, and their having channels between them would be advantages not to be found at many places on this coast.

The presence of the new Brazilian quarantine station might also occasionally put a steam launch at the disposal of investigators.

Ilhetas Point is at the southern end of the Bay of Tamandaré. Here there are two coral reefs: one small one connected with the shore, the other three hundred metres outside, separate from the shore reef, and about three kilometres long. Both these reefs are uncovered at low tide. The one on shore has the beach sand spread out over the top of it. On the south side of Ilhetas Point the inner reef is but slightly uncovered (one decimetre) at ordinary low tide. This part extends out from the beach, with which it makes a low angle for three hundred metres.

These onshore coral reefs are all dead. But few living corals are found in the shallow tide-pools over their surfaces, and these are the hardy *Porites* and *Favias* in small heads. The bodies of the reefs are solid, and their surfaces are thinly covered with seaweeds and sponges.

South of Ilhetas Point the coral reef stands further and further out from the beach, until it ends, after several small breaks, at the Caixão de Una.

South of the Caixão de Una the reef begins again in force and with small breaks continues for a distance of twenty-four kilometres to the Barra Grande, east of the city of Maragogý. Throughout this entire distance the beach sands are very calcareous, often almost entirely of triturated shells and corals.

At São José Point the seaward face of the reef is less than one kilometre out from the beach. It is one hundred metres wide on the highest part and stands about two metres out of water at low tide. The top of this reef is exceedingly rough and jagged and is covered with barnacles. The surface is all dead save the *Porites* and *Favias* found in the tide-pools. From the outer face of the reef to the shore the bottom is most of the way covered with corals in patches of various sizes, the tops of which are uncovered at the low spring tides. In the channels between these higher portions live some corals. The channels are of all widths, from a few decimetres to seventy-five metres or more.

The corals are burned at São José for lime, and as the large solid heads make better lime than the average of the reef it is probable that the finer heads have been removed for this purpose.

On the beach at São José the calcareous sands have formed a soft rock full of shells and calcareous Algae.

At the point of land next south of Rio Persinúnga there is a coral reef uncovered at low tide within a stone's throw of the beach, and round the bend in the shore this reef connects with the beach. The part here exposed is only about one hundred and fifty metres long by fifteen metres wide. The great reef opposite this point stands well out of the water at low tide. Five kilometres south of the mouth of the Rio Persinúnga the coral reef is double.

At Ponta do Mangue the outer edge of the coral reef is just one kilometre from the beach. The tide was not very favorable for an examination when this reef was visited. The width uncovered was one hundred and fifty metres, but at the lowest tides the width is very much greater. It stood 1.3 metres out of water, but it is considerably higher at the lowest tides, — probably as much as three metres.

The surface of the reef here is exceedingly irregular and etched, and is all dead save the Serpulae and barnacles that grow over the dead corals, and the few *Porites* and *Favias* and such other forms as thrive in tide-pools. Landward of the main wall of the reef the coral rocks rise in patches that are separated from each other by a labyrinth of channels of various widths.

A chemical analysis has been made in duplicate of a typical specimen of the rock of which this Ponta do Mangue reef is composed with the following results: —

ANALYSIS OF THE REEF ROCK FROM PONTA DO MANGUE, STATE OF ALAGÔAS, BRAZIL.

Sample collected by J. C. Branner, July 28, 1899. R. E. Swain, analyst.

	No. 1	No. 2
Calcium oxide (CaO)	46.01	46.03
Magnesia (MgO)	6.95	7.05
Iron (Fe_2O_3)	.85	.88
Alumina (Al_2O_3)	.56	.59
Sodium ([1] Na)	trace	trace
Carbon dioxide (CO_2)	42.94	42.96
Silica (SiO_2)	1.27	1.29
Phosphoric anhydride (P_2O_5)	.27	.26
Chlorine (Cl)	.31	.28
Water (H_2O)	.79	.77
Total	99.95	100.11

If all the calcium present were there as carbonate, and the rest of the carbon dioxide as magnesium carbonate, it would be equivalent to: —

Carbonate of lime ($CaCO_3$)	82.19
Carbonate of magnesium ($MgCO_3$)	12.98

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[1] Probably as chloride.

South of Barra Grande the line of coral reefs continues with breaks to the Porto de Pedras at the mouth of Rio Manguába. South of that place they are almost continuous to the mouth of Rio Camaragibe, — a distance of twenty-four kilometres. The seaward face of this reef averages something more than a kilometre off the shore.

At the Barreira do Boqueirão an inner reef, having its northern end well off shore, swings round and comes squarely against the beach at its south end, the beach sands lying on top of the dead coral reef.

At São Miguel dos Milagres (S. lat. 9° 18′ 30″) the coral reef is rather closer to the shore than usual. One kilometre south of there a coral reef is uncovered on shore for a short distance; its south end swings outward away from the beach into deep water.

Three kilometres south of São Miguel there is a coral reef uncovered on the beach at the mouth of a small stream. This piece of reef has been dead for a long while. Its surface has been pitted and worn by waves and sand, then buried beneath the encroaching beach sands, and now again it has been partly uncovered by the shifting currents. The freshly uncovered surface shows the composition of the reef much better than it can be seen upon the ordinary dead or even upon living reefs. The rock is mostly coralline and most of the coral imbedded in this mass is *Porites*. The *Porites* form less than half of the rock, — perhaps a third of it.

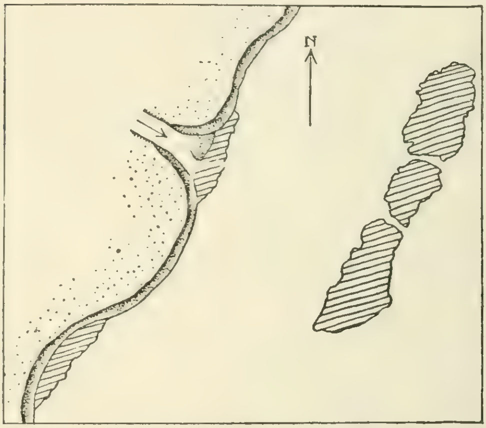

FIG. 97. Map showing positions of two coral reefs near São Miguel; the reef on shore is dead and is partly covered by sand.

This piece of reef runs out more than one hundred metres from the shore at mean tide, and at low tide a width of nearly five hundred metres is exposed.

One kilometre south of this exposure the sand flats exposed at low tide connect with and overlie the offshore dead coral reefs. The dead reef is exposed along the beach for more than two kilometres, and the water between it and the main reef outside (seaward) is very shallow and full of coral rock.

At Marceneiro Point coral reefs are exposed on the beach at low tide with the calcareous beach sands lapping over them. In the bank above the beach are exposed the partly consolidated calcareous sandstones shown in Fig. 58, p. 90. *Porites* and corallines are the commonest forms in the reef here.

At the bottom of the embayment south of Marceneiro there are coral reefs along almost all of the beach, and soft calcareous sandstone is exposed in the 1 to 2.2 metres bank above it. These coral reefs rest directly upon Tertiary shales.

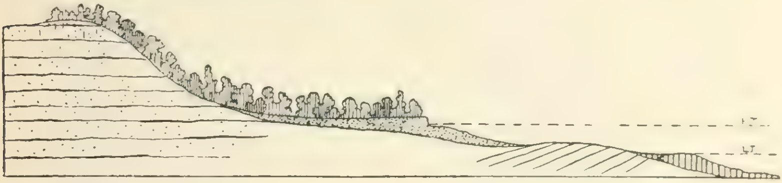

FIG. 98. Section showing the relations of the coral reef to the Tertiary at Barra do Passo.

There is a decided break in the coral reefs off the mouth of Rio Camaragibe, and they appear to begin again only five kilometres south of that stream. Thence southward to Ponta Verde north of Maceio the coral reefs are more broken and fragmentary than they are to the north. These fragmentary reefs were not examined except where they lie along the beach. Some of the beach exposures are of more than usual interest on account of their showing the relations of the coral reefs to the stone reefs and to the eroded Tertiary strata of the land.

South of Rio Santo Antonio Grande the coral reefs for two or three kilometres are almost connected with the beach, — perhaps quite so at the lowest tides.

At the point 1.4 kilometres south of Rio Sapucahý there is a sandstone reef overlying the coral reef. In view of the importance of this locality in showing the geologic relations of the stone and coral reef, I repeat here what has been given in the description of the Sapucahý stone reef: "Following the beach southward from the mouth of the Sapucahý [a small river of the State of Alagôas about thirty kilometres northeast of Maceio] it curves gradually seaward and then back landward again, forming a sandy point, part of which is shown on the accompanying map. At a distance of 1.4 kilometres from the mouth of the Sapucahý, this sandy point laps over one of the coral reefs that here run parallel with the coast. And just at this point on the beach begins another reef of sandstone. This particular reef is eight hundred metres long, not including some detached fragments lying beyond its southern end, and not shown on the map herewith, which would give it a total length of something more than a kilometre.

"A fact of unusual interest in regard to this bit of reef is that *it overlies a dead coral reef.* The overlap is plainly visible at many places where re-entrant angles have notched the stone reef, or where large fragments have been left isolated but fast to the coral reef. The coral reef visible here at low tide is from one hundred to two hundred and seventy metres wide, measured from the outer margin to where it is overlapped by the stone reef or by the beach sands. This coral reef is almost perfectly flat and level. Not a single living coral could be found on its upper surface; the coral most abundant in the rock itself is *Porites.*

"Outside or seaward of this reef is still another coral reef with which the inner one is not connected, at the water's surface at least.

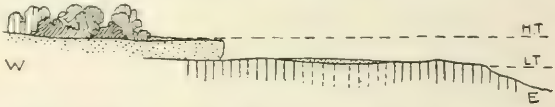

FIG. 57. Section across the stone and coral reefs at Sapucahý. The vertical shading on the right represents the coral reef.

"The sandstone reef lies at a higher level on the beach than the coral reef, and has throughout most of its length a decided seaward dip. At the southern end of its contact with the beach, however, the dip is reversed and the bedding looks very much as if it had been formed by sand washed over and behind a low beach or spit. The rock is in some places rather soft, in others it is quite hard and rings when struck with the hammer."

At Paripueira and southward the coral rocks are exposed at the lowest tides in many places and over large areas. At this place there is a considerable business in the burning of coral rock for lime.[1]

Off the mouth of Rio Pioquinho there are at least three coral reefs, the one nearest shore being three hundred metres out from the beach. Off the sandy point near Pioca there is one coral reef one hundred and fifty metres out from the beach, and the interval contains many isolated points of coral rock, while outside is a second reef about four hundred metres from the beach. These reefs are broken in front of the bay just south of Pioca, and south of the bay they continue again as three or four overlapping reefs.

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[1] The extraction of these rocks in the State of Alagôas is under the supervision of the Captain of the Port at Maceio, and the burners are taxed by the government in proportion to the size of the kilns burned.

Just above the mouth of Rio Santo Antonio Mirim that stream passes over a submerged reef. This reef was under water when it was passed, but judging from its jagged uneven surface over which we had to wade it is thought to be a coral reef. Both ends of the reef are covered by sand spits.

At Riacho Doce, south latitude 9° 36′, and from there to Garça Torta are several exposures of coral reefs on shore in addition to the large reefs outside.

As pointed out in the geological introduction, the rocks exposed along this part of the coast are probably of Tertiary age, beginning with heavy basal conglomerates containing large boulders of granite. Resting upon these conglomerates is a series of sandstones and bituminous shales wrinkled and faulted. These sedimentary beds have been cut off by the waves, and on top of the eroded surface have grown the coral reefs. In places the corals cover the granite blocks washed out of the basal conglomerates. At one place for a distance of thirty metres there is a sandstone reef on top of a coral reef which in turn rests unconformably on the upturned edges of the Tertiary shales. At another place the sandstone reef has been more or less shattered by the waves, but fragments of the stone reef rock from three to eight metres long overlie the coral reef, and in some cases they overlie coral reefs that rest upon granite boulders for a distance of two hundred metres. Again, two hundred metres north of Garça Torta there is a coral reef exposed at the edge of the beach for a distance of one hundred metres. The relations of this reef to the other rocks cannot be seen. At low tide it is one metre out of water.

Out seaward from these beach exposures are more than twenty patches of coral more or less isolated. They are generally not more than seventy metres across, — some are less than seven metres, — flat on top with openings between them. These patches extend a kilometre out from the beach. South of Garça Torta are similar patches. The following is an outline sketch of one of these small patches.

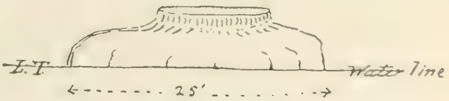

FIG. 99. Coral reef covered by worm tubes south of Garça Torta.

The harbor at Maceio is formed by the southern end of a coral reef. This reef is about three kilometres long and varies in width from eight hundred metres at its northern end, where it joins the beach, to only a few metres in its narrowest parts. At one point east of Jaraguá there is a big solitary mass of coral rock rising three metres above the general level of the reef. Mr. F. Ambler of the Alagôas railway kindly made photographs of this block from which the illustrations on pages 160 and 161 were made. The form shows that it has been undermined and one end of the block has settled, lifting the other end into its present position.

South of Maceio the reefs have not been examined. I was credibly informed that the one at Rio de São Miguel was of sandstone, and that south of that place the reefs are very fragmentary. It is also a remarkable fact that there are no coral reefs (known) between the mouth of the Rio São Francisco and the city of Bahia.[1]

The Bahia reef. — At Bahia there is a great coral reef off the east shore of the island of Itaparíca. This reef was studied by Mr. Rathbun in 1875–76, and a paper on it was published by him in the "American Naturalist."[2] Part of Mr. Rathbun's paper appeared in the Archivos of the National Museum at Rio de Janeiro.[3] I did not therefore visit the Itaparíca reef, but have depended upon Mr. Rathbun's paper, which is full and is given here at some length: —

> "The long island of Itaparíca, often called the garden of Bahia, fills up almost the entire southwestern quarter of the large Bay of Bahia, and contracts its entrance to a width of about five miles. Its outer coast, running obliquely, faces for the most part the open sea, and is at the mercy of its boisterous waves. Skirting the central portion of this coast for a distance of nearly nine miles is a slightly elevated coral reef, long since abandoned by true living corals and given over to another class of workers, who are putting on the finishing touches and coating it with a hard and durable substance.
>
> "This reef begins directly opposite the city of Bahia, in front of a little rocky point named Jaburú, and stretches away southward, in the general trend of the shore, enclosing behind it a narrow and shallow channel which, at the most, is scarcely one-fourth of a mile in breadth, and generally less. It is most perfect toward the northern end, and has, at irregular intervals, numerous breaks or openings which admit the smaller boats that ply along the shore. Approaching close to Penha, another rocky point about three miles from Jaburú, it ends abruptly; but commencing again to the south, it runs onward to the Ponte da Cruz, terminating for good on the rocky shore. The study of the geology of

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[1] For a description of the Maceio reef see Prof. A. W. Greeley's paper, — appendix to this paper, p. 268–274.

[2] Richard Rathbun Brazilian corals and coral reefs. American Naturalist. September, 1879. XIII., p. 539–551.

[3] "O recife de coral do Mar Grande." Archivos do Museu Nacional, III., p. 174–183. Rio de Janeiro, 1878.

the island has shown that the reef follows the submerged, out-cropping edges of a series of heavy beds of sandstone, which, at times, bring up on the shore in the form of rocky points. On this solid base the reef appears to have been built, and where, finally, at the south, the sandstone leaves the sea and lies upon the beach, the coral reef ceases to exist.

"The reef is slightly zigzag in its course, and both edges are very jagged, deeply indented and bordered by projecting or outlying masses; but so irregular in every part that it would be quite useless for us to try and describe it accurately. At the northern end it is generally elevated on the outer side and low and level on the inner. The higher portion varies greatly in width and height, and is never flattened on top; it rises rapidly, often abruptly, from the water, but descends more gradually on the inner side to a level of about one foot above ordinary low tide. From here there extends inward a very flat surface, which is generally quite broad but may narrow down or even nearly disappear. Almost everywhere along the inner edge, but more commonly at the ends of the reef and about the openings through it, we find many outlying masses which are often partly continuous with the low, inner surface, but more frequently quite detached. They attain all heights up to that of the lower surface, but never reach above it; the average depth of water around them is between three and four feet. The outliers on the outside of the reef are merely low, ragged, angular projections from the reef itself, and are never much exposed, even at low tide.

"Between the two divisions of the reef, the elevated outer portion and the flat inner one, there is the most marked contrast. While the latter has been completely smoothed and rounded off, so that scarcely any angles remain upon it, the former retains all the possible roughness that could be brought together on so narrow an area. The entire raised mass of rock is full of holes of every imaginable size and shape, the margins of which are always acutely angulated. Every little surface that is not pointed in itself is surmounted by a large and strong barnacle with sharply-edged valves, and large clusters of digitate projections stand up at frequent intervals. This combination of surface is a very uninviting one to look upon, but it is far less pleasant to climb over it or walk along its outer part. The outer slope is by far the most irregular, as the waves, aided by an army of sea-urchins, have broken into it and hollowed out thousands of ragged holes, which, lying concealed beneath the seaweeds, might lead to many accidents were the reefs more frequented.

"The outer portion of the reef is of a dark and rather rich brown color when wet by the waves, but nevertheless has quite a dead appearance. Examining carefully this brown rock, it is seen to consist generally of an accumulation of very small worm tubes, closely packed together and forming a very hard mass. The surface of the low inner level is of a much lighter color, a rather faded brown, and looks even more lifeless than the part we have been describing; no barnacles or other larger animals grow upon it.

"What forms of life occur about the reef? On the outer side, reaching to a height of a foot or slightly more above ordinary low tide, is a luxuriant growth of seaweeds. Over the same zone, but not so apparent, spread encrusting nullipores, which, though resembling lichens in form, are so highly charged with lime as to produce a hard coral-like substance. This is one of the most important organisms living on the reef at present, and while aiding to protect it from wear is also building it up. The barnacles and worm tubes of the upper portion we have already referred to, and we have also stated that over the inner surface there seems to be nothing alive. As we enter the many open pools and passage ways of the inner margin there is scarcely more to be seen. Only here and there does a small mass of coral grow, usually a Siderastraea or a Favia. Seaweeds and delicate tufted hydroids and bryozoans hang from the sides of the pools, and a few shell-fish and star-fish lie on the sandy bottom. Small, brilliantly-colored fish dart hither and thither, but the life is not what we are taught to expect about a coral reef.

"The features we have so far been giving are those of the northern section of the reef. Going southward a short distance, the elevated outer mass gradually diminishes in size, until it is reduced to a slightly raised border along the seaward margin of a broad and flat reef. Still farther south the entire lower surface, without the raised margin, seems lifted bodily upwards to form a high massive wall, like that of an immense fort, flat above and perfectly square at the sides.

"Between the points of Penha and Cruz we find a varied structure, generally, however, only a repetition of the forms already described. The reef is often two or three times as broad as at Jaburú, but near its southern end it becomes very irregular and much broken up, existing as a line of detached reef masses. The passage ways through the reef are sometimes mere simple breaks, cut as squarely and neatly as though the work of man; at other times, however, the edges of the reef bordering them are carried obliquely inwards some distance toward the beach, enclosing a narrow entrance channel. These inner prolongations, although generally low and level, have the same structure as the main reef.

"Within the reef the water is always shallow; frequently the bottom lies so high as to be quite exposed at low tide, and it is covered nearly everywhere by a thick deposit of coral fragments, cemented together by carbonate of lime. The corals are not in place but lie heaped together in every conceivable way, as though they had been violently broken from the reef at some former time and thrown inside by the waves. All the commoner forms are there, Millepora, Siderastraea, Orbicella, and Mussa being the most conspicuous, and they are sometimes nearly perfect, but most often broken into irregular masses, large and small. The majority are also coated over with a thin nullipore crust, as though they had been dead a long time before they were swept from their proper dwelling place. This coral deposit has considerable thickness near the middle of the channel and thins out gradually toward the beach.

"The extreme southern end of the reef is very low, and near to the beach. It breaks down abruptly on the outer side, but on the inner is bordered by a thick, consolidated layer, which reaches so nearly its own level that it is often difficult to make out the dividing line between the two. A close examination, however, discloses the upright corals in the one and the prostrate fragments in the other.

"A great difficulty stands in the way of our determining the intimate structure of this nearly extinct reef, whose outward appearance and surroundings we have so fully discussed. It has evidently not been formed entirely by those agents at present occupying its upper and outer surfaces; but the remains of the real builders, whatever they were, are entirely covered up and hidden from view, excepting at the one point at the southern end just mentioned. We must resort to artificial sections, no easy undertaking in a coral reef.

"Breaking with hammer and chisel into the higher part of the reef, we obtain specimens of a very hard, compact limestone, partly of a nearly homogeneous structure, partly marked by straight or wavy lines of lighter and darker coloring; these two kinds of structure are intermingled with one another without order, sometimes one, sometimes the other predominating. The former has resulted from the masses of serpula tubes by the complete filling in of their winding cavities and the spaces between them by carbonate of lime, until no trace of the original structure remains. The latter is due to the growth of incrusting nullipores, one thin layer upon another, until quite a thickness of rock has been the result.

"It is evident that the serpulæ and nullipores were at one time living together over the surface of the reef, and by their combined action has been formed most, if not all, of its outer raised portion, which is sometimes over four feet high and twenty-five feet across. The barnacles are generally broken from the reef when dead, but are sometimes overgrown by worm tubes and thus become imbedded.

"Here and there, the slaves, in procuring lime, have quarried into the low inner part of the reef, and even into the high wall-like portion. Good sections for study are thus formed, and they tell us of what the reef consists. Many large heads of Orbicella, Acanthastraea, and Siderastraea stand there exposed in their original positions, and when cut through show their structure to be as open and perfect as though they were still living. With them are many large millepores and nullipores, and all the intervening spaces are filled in with a compact calcareous substance.

"Our structure began as a true coral reef, stretching along the submerged rocky ledge. The water was very shallow, however, and the reef soon reached a level above which its corals could not live. Over them nullipores began to grow, but probably while the reef was being raised by other causes than those of growth, large numbers of these dead and partly entombed corals were swept inward by the waves. Nullipores continued to thrive and serpulae came in to aid them, but with these forms we are already familiar."

Reefs between Itaparíca and Caravellas. — South of Itaparíca the coral reefs have been but little studied, probably on account of the difficulties of transportation along this part of the coast.[1]

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[1] One can get an approximate idea of these difficulties when I say that the Bahia company whose steamers run as far south as Viçosa and the Abrolhos have

Extensive coral reefs are reported at and north of the Port of Camamú. Spix and Martius report from the "inland water of Camamú *Madrepora uva* [*Dichocœnia uva* E. & H.] which we noted near *M. astroides* and *acropora*."[1] The next place south of there at which corals are known is at the Lagôa de Itahype, south latitude 14° 40′. This place was visited by Spix and Von Martius in 1818, and is described by them.[2] The location is so remarkable — the bottom of a fresh-water lake, seven kilometres from the sea — that I give at length what they say of it. This lake was formerly known as Lagôa de Almada, and it is under this name that Spix and Martius speak of it. It is now more commonly known as Lagôa de Itahype.

> "On the shore it [granite] is exposed here and there in great naked banks through which trough-shaped depressions and zigzag channels seem to show a connection of the ocean with the lake in early times. There is still stronger proof of this connection in the form of the shore which toward Itahype and the sea on the southeast is flat and sandy, and especially in the presence of extensive coral reefs. These reefs may be seen at several places in the lake at a depth of from six to twelve feet, and the rock is quarried for lime and for building stone. It is broken up with wedges and crowbars and the pieces raised by divers. . . . The business is not very profitable because the coral banks in the great bay of Camamú are more easily worked. Those seen in this lake are exclusively madreporic. . . . *Madrepora* [Heliastraea] *cavernosa*, *hexagona*, *astroites*, Lam. n. s. There are also in the neighborhood banks of sea-mussels cemented in quartz sand but being impure and difficult to break they are not quarried. The water of the lake . . . is now fresh probably through the agency of Rio Itahype, which has gradually washed it out, or freshened the water cut off from the sea."

The reefs shown on the charts at Ilheos are crystalline rocks, — not corals. South of Ilheos the first coral reefs are those off Ponta Guaiú and are known as the Araripe reefs. They form part of a large group that extends across Ponta de Santo Antonio northwards for some nine

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no set dates for sailing. One depending upon these steamers is liable to have to wait at Bahia from one to three weeks or even a month, expecting the announcement of a date any day, and consequently unable to leave that city in order to utilize the time elsewhere. After nine days waiting at Bahia, I took a steamer for Ponta d'Areia and reached that place in eight days from Bahia. At the last-named place I was compelled to wait twenty-five days for a steamer to Rio de Janeiro. The trip that ought to have taken at the most seven or eight days consumed just thirty-eight days.

[1] J. B. von Spix u. C. F. P. von Martius. Reise in Brasilien. II., p. 710. München, 1828.

[2] Reise in Brasilien. II., p. 684–685. München, 1828.

kilometres, and southward to and including the great Itassepanema reef at the northern end of the Bahia de Cabral. Their total length is about twenty kilometres to the Boqueirão Grande entrance to that bay. These reefs all draw away from the coast somewhat at their northern ends. They are all covered at high tide, and uncovered at low tide. There are various small passages through the Araripe reefs, and there is a canal between the reef and the shore for small crafts only. The northern end of the Araripe group is not shown on the charts of the coast. The southern reef of this group is known as Itassepanema. There are two yellow sandbanks on it, one of which is known as the Corôa Alta; this bank is not covered at ordinary high tide.

The Itassepanema reef is somewhat higher at its southern than at its northern end. Its surface is very flat and smooth.

The Alagadas reefs south of the Boqueirão Grande are also of coral, but they are small as compared with the Itassepanema reef.

At the southern end of the Bahia de Cabral a line of coral reefs stands out from Ponta Vermelha and Corôa Vermelha in a nearly northeast direction. This reef continues from the point marked "Vermelha Bank" on the chart to and south of the mouth of Rio Manguinha. Its total length is about eight kilometres. It curves outward and away from Ponta Grande and leaves between it and the beach a canal for small crafts at high tide.

The Recife de Fora, or Baixo de Fora, as it is called on the chart, just north of Porto Seguro, is a coral reef, reported by the coast pilots to be "not less than half a league wide," east-west.

The next coral reefs south of Porto Seguro are those known as the Itacolumis, south latitude 16° 53′. I did not visit the Itacolumi reefs.

Coral reefs off Caravellas. — *The Parcel das Paredes* is the most extensive group of coral reefs on the Brazilian coast. They have a total length of about thirty-three kilometres, and a maximum width of about twenty kilometres. I visited them only once, — in September, 1899, — but I traversed almost their entire length and breadth in a whale-boat that allowed me to pass freely through the shallower parts of the channels. I did not, however, see the extreme eastern edge of the reefs where they receive the heaviest surf.

The highest part of the Parcel das Paredes reefs is at their northern end, and is known as the Recife da Lixa, or Shark Reef, on account of the great number of a certain kind of sharks about this part of it.

But the whole of this group from one end to the other, and without any exception, is completely covered by water at high tide. It will be seen that these reefs are a long way out from the shore. In order to spend a second day on them it was necessary to anchor our boat and remain there over night. When the tide was high, except that the sea was not very rough, to all appearances we might have been anchored in the middle of the ocean.

The water was a little short of two metres deep on the higher parts of the reef at high tide; judging by the posts planted on the reef, I take it that the tides here rise about three metres.

These reefs are traversed by irregular channels from one to ten metres deeper than the top of the reef, and varying in width from three or four metres to half a kilometre or more. The whale-fishers of the Barra de Caravellas have planted here and there along these channels tall poles to serve as guides in sailing across the reefs when the water is shallow on top of the rocks, and to mark anchoring places for their boats at night.

When the tide is ebbing the first visible signs of the reef are muddy-looking splotches in the water; these get browner and yellower as the water gets shallower, until the rocks begin to appear at the surface. When the reef is quite uncovered it has a deep yellow color, — between lemon and orange. The water itself looks yellow and muddy over the reefs, but this is deceptive, for it is perfectly clear, — at least it was so during my visit.

The Lixa reef is the flattest and smoothest I have seen on the coast of Brazil. Except on the edges, where it is always more or less ragged, it has the appearance of being one solid compact mass of coral rock built up to an even level. The view over its surface at low tide reminds one of a great prairie covered with short dead grass, the sky line unbroken save here and there by a few black points, — blocks of the reef rock broken out by fishermen in search of squid or fish.

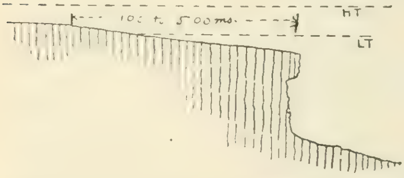

Fig. 100. Profile of the edge of Lixa coral reef.

The top of the reef is dead so far as the corals are concerned. Only two forms were found alive in the shallow pools on the surface, — *Porites* and *Favia*, — and these are all small and apparently stunted. Other polyps are also abundant, but the patches are small and the species few. Living corals are found only along the edges and over the bottom of the channels that cut the reef, and in the isolated patches that rise near the margins of the reefs. These living corals are fully a metre below the reef's flat surface.

The surface of the reef — that is, of the large solid portions that rise above water — usually slope off rather gently into the water at all points where it was examined. The slope of from three to ten degrees begins from fifty to one hundred metres back from the edge of the water at low tide.

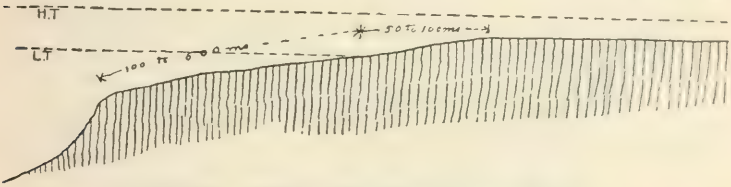

Fig. 101. Profile of the edge of Lixa coral reef.

At several places this gentle surface slope continues beneath the water for a hundred, or even several hundred, metres, where it comes to a sudden drop off into deep water.

The patches of living corals that rise from the deeper waters in the channels and at the reef margins are of many sizes. Their forms vary, of course, but not to any remarkable extent. The following are true profiles as nearly as they can be made without minute measurements, and they include as great a variety of forms as was seen.

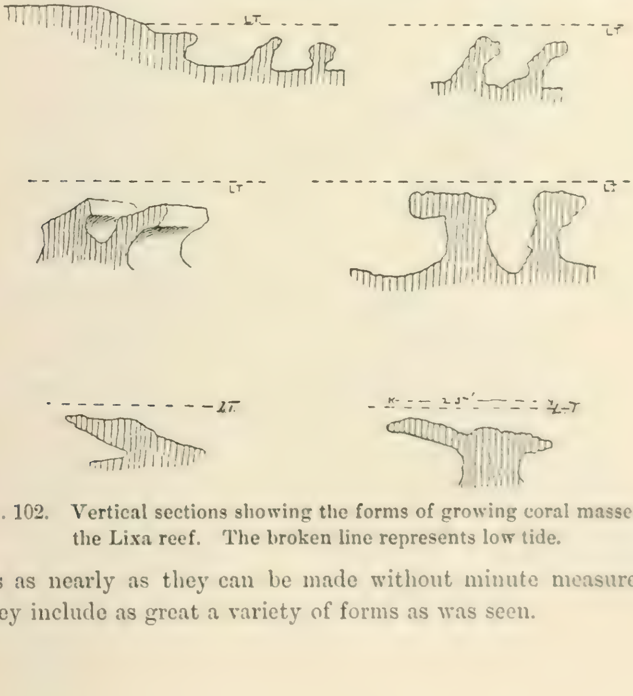

Fig. 102. Vertical sections showing the forms of growing coral masses on the Lixa reef. The broken line represents low tide.

It is quite noticeable that these growing projections lean with some uniformity in a certain direction. These directions, however, are not always the same. The most marked cases I noted were in east-west channels, where most of these points leaned toward the west. I suppose these forms to be due in some way to the influence upon the growing polyps of the movement of the tidal currents through the channels.

The forms of the growing portions as seen in plan are much more varied; indeed, there seems to be no limit to the shapes of these masses below a certain level. This certain level I take to be the depth at which the polyps are injuriously affected by any agency whatever at the lowest spring tides.

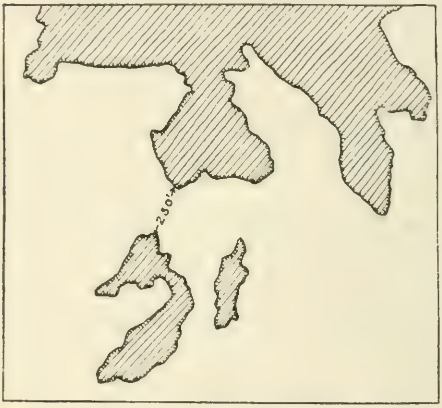

Fig. 103. Plan of a part of the west edge of Lixa reef.

These growing portions start out from the larger reefs like long knotted fingers, or rise like solitary stumps from the bottoms of the channels. The following are plans of some of them.

Inasmuch as these growing portions of the reef are in the deep channels that traverse it, the channels themselves vary greatly in outlines — width and depth. Some of the measurements may here be given:

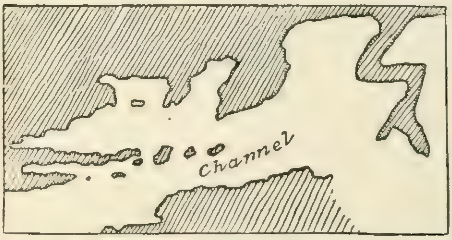

Fig. 104. Form of one of the channels of Lixa reef. Low tide.

Channel 300 metres wide, 8 metres deep at low tide; a few isolated coral masses rising from the bottom.

Channel 80 metres wide, 3 metres deep.

Channel 85 metres wide, 8 metres deep; with chapeirão.

Channel 65 metres wide, 9 metres deep; chapeirões at the margins. The bottoms of these channels are as nearly flat as may be; the depth measurements next to the walls are but little different from those in the middle.

The anchor always brings up from the bottom blue calcareous mud;

about the edges of the reefs also, wherever there are accumulations of sediments they are in the form of calcareous mud that is blue a few centimetres below the surface, but cream-colored to yellow and buff on the surface.

The chapeirões or isolated masses are at various depths beneath the water; some of them even reach the surface at low tide. Those whose summits are uncovered at low tide have very flat tops. Their sizes and forms in plan are simply endless. In some places they are so abundant that they are only from one to six metres apart, and pretty evenly spaced; again they are but sparsely scattered over large areas.

It is on these growing isolated masses that the best examples of coral heads are found. I was rather disappointed, however, in the corals of the Lixa reefs. Really fine examples can be had here only at the lowest spring tides. The biggest heads accessible were not more than from forty-five to sixty centimetres in diameter.

The facts that most impress one in regard to the Parcel das Paredes reef are (1) that the upper portion of it is completed and dead, (2) that its growth is now confined to filling in the channels that separate its larger portions, and (3), that the final completion of the still growing portions consists in the extension of the isolated stumps until the spaces between them are closed. In many places these stumps are so thick that the reef may be said to be in its last stages of growth.

The reef is weaker in its development on the landward side than from the centre eastward, and its landward side is about a metre lower than the highest parts. The smoothness of the surface of these reefs as compared with the reefs of the northern coast is remarkable. And this smoothness is noticeable in all the reefs seen from Cabral Bay southward.

As a place for collecting corals the Parcel das Paredes is no better than scores of more accessible reefs along the coast of Pernambuco and Alagôas. It has the advantage of not having been so much explored by lime-burners as many of the northern reefs, but it has the disadvantage of being a long way from land, with inconvenient sand-bars between the land and the reefs.

An elevation of eight metres would kill nearly all of the living parts of the Paredes reefs, but an elevation of two metres would not affect them seriously.

I was told by a pilot who has lived at the Barra de Caravellas for forty years, that the currents inside of the Abrolhos and Parcel das Paredes reefs set strongest to the southwest in May, June, and July, that they run in the same direction at other times of the year, but not so strongly.[1]

Corôa Vermelha, also called "Sebastião Gomes," a small island off Viçosa, south latitude 18°, is a coral reef. The reef is quite flat, and is entirely covered by water at high tide. The margins are said to have steep, almost wall-like faces.[2] Some five or six years ago a Rio company shipped the reef rock from Corôa Vermelha to Rio de Janeiro, where it was burned for lime.

The Abrolhos reefs. — The Abrolhos reefs I have not visited. It was not possible to make an extensive study of them, and a visit of a day during my stay at Caravellas hardly seemed worth while.

Reclus speaks of the coral reefs of the Abrolhos as the most remarkable of this part of the coast; but as coral reefs, in size and interest they are hardly comparable with the Parcel das Paredes. He also says the Abrolhos are "trois ilots granitiques,"[3] which they certainly are not, though there is a sheet of olivine gabbro diabase overlying the sedimentary beds upon and about which the coral reefs grow.

In order to make these notes as comprehensive as possible, I add here what Hartt has written about the Abrolhos reefs.[4]

> "The islands of the Abrolhos lie about midway between the cities of Rio and Bahia, a little south of the parallel of Caravellas, and at a distance of about forty miles from the mainland. The position of the lighthouse on the island of Santa Barbara is, according to Mouchez, latitude 17° 57′ 31″ south, longitude 40° 58′ 58″ west from Paris. These islands are situated apparently near the middle of the submerged border of the continent, which here, over a very large area, lies at a depth of less than one hundred feet. They are four in number, with two little islets, and they are arranged in an irregular circle, three of them close together. All are rocky and rather high, Santa Barbara, the principal one, being 33.22 metres in height. The length of this island is about three quarters of a mile. Its outline is irregular, and it is very narrow. It is composed of beds of sandstone, shales, and trap, which dip approximately north-northwest, at an angle of from ten to fifteen degrees. Owing to this northward dip of the strata, the northern side of this island presents a steep slope to the sea, while on all other sides it is precipitous. The island is almost divided in two in the middle, by a cove indenting it on the southern side. . . .

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[1] For further details and determinations of corals collected on these reefs, see Hartt's Geology and physical geography of Brazil, p. 203–211.

[2] Capitão Tenente Collatino Marques de Souza, Revista do Instituto Geographico da Bahia, 1895, II., p. 27–29.

[3] Nouvelle Géographie Universelle, XIX. Amérique du Sud, p. 268. Paris, 1894.

[4] Ch. F. Hartt. Geology and physical geography of Brazil, p. 174–200. Boston, 1870.

"In lithological characters the Abrolhos beds resemble the sandstones, etc., of the Rio São Francisco at Penedo, . . . and which contain similar plant remains. They have been disturbed by the same upheaval, and I have little hesitation in referring both to the cretaceous. . . .

"As we go northward from Cape Frio, the madreporians become quite common on the rocky shores, though the species are not numerous, and they are associated with species of *Millepora*, *Zoanthus*, and *Palythoa*, and various gorgonians. I have already called attention to the coral fauna of Guarapary and Victoria, and I have stated that I have no evidence of the existence of any banks of living corals or reefs south of the region of the Abrolhos. Here the conditions for the growth of coral reefs on a large scale are remarkably favorable. Over large areas the water covering the great submarine shelf, on which the islands are based, is much under one hundred feet in depth, and it is warm and pure. So it is not to be wondered at that very large coral reefs, both fringing and barrier, are found here.

"When the tide goes out there is seen extending round about one half the circumference of the island of Santa Barbara a fringing reef. . . . One may then walk out on its level surface as on a wharf, and from its ragged edge look straight down through the limpid green water and see the sides of the reef and the sea bottom covered with huge whitish coral-heads, together with a wealth of curious things not to be obtained without a dredge.

"The surface of the reef, though flat, is somewhat irregular. It rises but a short distance above low-water mark, and it is overgrown with barnacles, shells, mussels, and serpula-tubes, together with large slimy patches of the common leather-colored *Palythoa*. The reef abounds in small pools, some shallow and sandy, others deep, rocky and irregular. The former often contained scattered masses of corals, particularly *Siderastraea* and *Favia*, and they abound in small shells, crabs, Ophiurae, etc.; but the deep pools are the richest in life. These are usually heavily draped on the sides with brilliantly tinted sea-weeds and corallines, the bare rock being gay with bryozoa and hydroids. The most common coral of these pools is *Siderastraea stellata* Verrill. . . .

"The material composing the reef is an exceedingly hard, whitish limestone, ringing under the hammer, and, so far as I had an opportunity to examine it, for the Brazilian reefs are never broken up by the surf, — showing no distinct trace of organic structure. The Santa Barbara reef extends around about one third of the island, and on the northwestern side it reaches across to the 'Cemetery,' so that when the tide is down that islet is joined to the main island by a broad, level platform of rock, diversified by tide-pools, and forming an excellent collecting-ground for the naturalist. The reef, built up principally of *Acanthastraea*, *Siderastraea*, etc., has completed its growth on arriving at low-tide level, the upper surface being still farther added to by serpulae, bryozoa, corallines, barnacles, etc., together with the coral-sand and debris of shells accumulating on the reef.

"So far I have spoken only of fringing reefs, but there are other coral structures of greater interest in these waters. Corals grow over the bottom in small patches in the open sea, and, without spreading much, often rise to a height of forty to fifty or more feet, like towers, and sometimes attain the level of low water, forming what are called on the Brazilian coast *chapeirões.* At the top these are usually very irregular, and sometimes spread out like mushrooms, or, as the fishermen say, like umbrellas. Some of these chapeirões are only a few feet in diameter. A few miles to the eastward of the Abrolhos is an area with a length of nine to ten, and in some places a breadth of four miles, over which these structures grow very abundantly, forming the well-known Parcel dos Abrolhos, on which so many vessels have been wrecked.

"I visited in my launch the northwestern part of this reef, where the chapeirões were sufficiently scattered to allow me to sail about among them.

"Among these chapeirões I measured a depth of sixteen to twenty metres, and once, while becalmed, I found twenty metres alongside one chapeirão and three metres on top. The chapeirões, as a general thing, are rarely ever laid bare by the tide. They are here, as elsewhere, of all heights and dimensions; but in no case do they reach low-water level, nor according to the testimony of the fishermen and whalers, are they ever in any part uncovered. They do not coalesce here to form large reefs as they do to the west of the islands. When the weather is clear and cloudless, and the water calm, these chapeirões can be readily distinguished at a considerable distance. The surface of the sea appears to be flecked by shadows from a sky full of scattered cloudlets, producing a striking effect. The water, being shallow and clear, and with a sandy bottom, is of a very light greenish tinge, like that of the Niagara River at Buffalo. The general color of the chapeirões is brown, from their being encrusted with patches of *Palythoa*, and their position is marked by brownish spots on the surface of the sea. In the daytime a launch may sail in safety among them in calm weather, and a small vessel may traverse some of the chapeirão grounds without danger, but large ships are likely to find themselves in a labyrinth from which escape is not easy. In windy weather the waves break over the chapeirões, but if there are white caps beside, and a cloudy sky, their position cannot be made out, and it is safest to keep well away from them."

The corals collected on these reefs by Hartt are described by Verrill.[1] The list is given below.

LIST OF CORALS COLLECTED BY C. F. HARTT ON THE ABROLHOS REEFS.

CLASS, POLYPI.

ORDER, MADREPORARIA.

Agaricia agaricites ? M. Edw. and Haime.
Siderastraea stellata Verrill, var. *conferta* Verrill.

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[1] A. E. Verrill. Notice of the corals and echinoderms collected by Prof. C. F. Hartt, at the Abrolhos reefs. . . . Trans. Conn. Acad. Arts Sci., 1868, I., p. 351–364, Pl. IV.

Pectinia braziliensis M. Edw. and Haime.
Favia leptophylla Verrill.
Favia gravida Verrill.
Favia conferta Verrill.
Acanthastraea braziliensis Verrill.
Heliastraea aperta Verrill.
Mussa harttii Verrill.
Symphyllia harttii Verrill.
Porites solida Verrill.

ORDER, ALCYONARIA.

Hymenogorgia quercifolia M. Edw. and Haime.
Gorgonia (*Pterogorgia*) *gracilis* Verrill.
Eunicea humilis M. Edw. and Haime.
Plexaurella dichotoma Kölliker.
Plexaurella anceps ? Kölliker.

CLASS, ACALEPHAE.

ORDER, HYDROIDEA.

Millepora nitida Verrill.
Millepora brasiliensis Verrill.
Millepora alcicornis Linn., var. *cellulosa* Verrill.
Millepora alcicornis Linn., var. *digitata* (*?*) Esper.
Millepora alcicornis Linn., var. *fenestrata* Duch. and Mich.

Thickness of the coral reefs of Brazil. — Near the rocky shores one can frequently see the thickness of the coral reefs, but these places do not help us to judge of the thickness of the same reefs a kilometre or two out at sea. It is evident from the physical conditions controlling the growth of coral reefs and from the shape of the submarine floor that the Brazilian reefs grow in the shallow waters along and upon the continental shelf. It is not perfectly clear, however, whether this shelf may or may not have been built up in places from great depths by an upward growth of the reefs during periods of coastal depression. The contour of the bottom on which the reefs started was not necessarily alike in all places, so that there is a chance for some local variation in the thickness of the same reefs, quite aside from any thickness attributable to the subsidence of the coast along which they grow. It is evident, however, that since Miocene times there has been an elevation of the coast that lifted the marine Tertiary sediments out of the water and subjected them to erosion both over the land surfaces and along the coast-line. Marine erosion has vigorously encroached upon the land since the elevation of the Tertiary beds, but it has always left a shallow shelf offshore. Then followed a depression which carried beneath the sea some of the valleys near the coast. Many low coastal islands were probably formed by this depression, but most of these islands have long since been removed by marine erosion. In this way it is believed that the Abrolhos islands were separated from the Brazilian mainland. Those islands are low, and the same Tertiary (?) sediments that form them lap back over the crystalline rocks of the mainland to an elevation of one hundred and fifty metres. The distribution of the Tertiary rocks along the coast of Brazil leads to the supposition that the valley that lay between the present Abrolhos islands and the mainland was a broad shallow one. I say shallow because all the valleys known in the coast Tertiary are shallow, — less than one hundred metres deep.

The conclusion seems warranted, therefore, that any coral reefs that may have taken possession of this submerged valley since its depression are necessarily of limited thickness, probably not exceeding one hundred or two hundred metres.

Since Pliocene times there has been a slight elevation of the land, but the coral reefs do not seem to have been near enough to the surface at the time of the elevation to have been lifted altogether out of the water by it. At least no reefs are now known along the Brazilian coast standing quite out of the reach of tide-water. There are several places at which there are dead coral reefs, but for aught that is now known they are dead only because they have reached the upward limits of coral growth. There are also some dead corals to be found among the debris of the elevated beaches of Bahia, but thus far no solid coral reefs have been found among these shell heaps.

The coral rock that rises above the reef and above tide-water at Maceio is not the remains of an elevated and eroded reef, but the uplifted corner of a piece of reef rock that has been undermined by the tidal currents.

In this particular case the thickness of the coral reef appears to be exhibited by the edge of the up-tipped block. It seems to show that the coral reef at this particular place is very thin and rests upon a base of soft material that the marine currents have been able to excavate.

The profile of the coast in the vicinity of many of the coral reefs also suggests that the reefs must be quite thin. Reference is here made to those places in which the reefs lie near a coast having steep bluffs facing the sea — such as exist along the greater part of the coast. The profile at

Rio Formoso, Maceio, and Tamandaré may be taken as the type of this kind of geographic relations of the reefs. The reefs in such places are usually long and slender, and it is believed that they are younger than the large reefs. These forms are so constant that one profile can be substituted for another without modification of any of the essential features. In the cases of the largest reefs, such as those of Cape São Roque reefs, the Parcel das Paredes and the Abrolhos reefs, the adjoining coasts are low, and the coral reefs are probably older and thicker than they are off the steep shores of the coast of Pernambuco and Alagôas.

In at least one instance it seems probable that the coral reef (that at Parahyba do Norte) has taken possession of and is now growing upon a submerged stone reef. Briefly stated, the reasons for this opinion are: —

I. A deep well sunk at Cabedello inside the reef penetrated only the soft coastal sands.

II. The reef lies across the ancient mouth of the Rio Parahyba do Norte, — the position in which the stone reefs of the coast are usually formed.

The coral reef could live in its present position, however, only after the formation of the Ponta da Matta spit, which turned the river waters away from the reef. The coral of the Parahyba reef is probably less than five metres in thickness.

The actual thickness of the reefs can, in my opinion, be ascertained with absolute certainty in but one way, and that is, by boring into the reefs *at a large number of places.* Some idea of their thickness can be had, however, by working out the geological and geographical history of the coast. The first method it has not been convenient to employ; the second one has been made use of in the present paper in so far as it has been possible to make out the coast history. We must conclude, therefore, that the coral reefs of the Brazilian coast probably nowhere exceed a thickness of one hundred metres. Most of them are much thinner and do not exceed fifty metres. The greater part of them are even thinner than this.

The age of the coral reefs. — The existing coral reefs are necessarily descended from the ancient ones. But the geologic and geographic history of the Brazilian coast cannot be traced with much precision further back than Tertiary times.

Magnesian limestones and dolomites found among the Cretaceous rocks of Sergipe and in the Cretaceous (or Tertiary ?) rocks of Pernambuco, and Rio Grande do Norte show that coral reefs existed on this coast in Cretaceous times and the present reefs must be descended from those of Cretaceous age. In the rocks known to be of Tertiary age there is but little evidence of the existence of coral reefs. The geographic development of the coast, however, and the distribution of the reefs at the present time lead to the inference that the reefs, as they are now known, began their existence after the elevation and erosion of the Eocene Tertiary beds along the Brazilian coast. This is suggested, if it is not proved, by the fact that the present reefs grow upon the marine shelf cut by the sea in the Tertiary and older rocks, or they occupy areas that were submerged after the erosion of the Eocene beds had been in process for a considerable period. There has been much encroachment upon the land by the sea, and this encroachment has been followed up sharply by corals taking possession of the submarine shelves wherever the conditions were favorable until we now have coral reefs growing close to the sea bluffs. The reefs at and about the Abrolhos group are built upon submerged Tertiary rocks. They therefore began in the latter part of the Tertiary and have continued down to the present time. This seems to be true of all the large reefs: those of the Abrolhos, Parcel das Paredes, and those at Cape São Roque; and these reefs are not only the largest, but likewise the oldest and probably the thickest of the reefs of the Brazilian coast. Many of these reefs, however, long ago finished their upward growth and are now growing only laterally.

For reasons already given the barrier and fringing reefs that grow near the steep shores appear to be newer than the large offshore reefs. No line of demarcation, however, can be drawn between the large offshore reefs and the near-shore barrier and fringing reefs. They all merge together both in physical characters, in thickness, and in age.

The coral reefs, therefore, antedate the stone reefs. This is shown by the occurrence of reef-building corals in the rocks of the stone reefs, and also by the relative positions of the two kinds of reefs, along the coasts. The coral reefs are also locally newer than the stone reefs, as is shown by the former growing upon the latter. The corals will continue to grow seaward from the stone reefs, while the latter will change but little. No elevated coral reefs are now known on the coast of Brazil. If the elevations of Pliocene times killed some of the reefs, they were again taken possession of and new reefs grew upon the old ones as soon as they were resubmerged.

The Brazilian coral reefs are almost everywhere narrow. The widest are those of the Abrolhos, Parcel das Paredes, Itassepanema, Itacolumis and Cape St. Roque, which are at most only about thirty-three kilometres wide. Some of the coral reefs connect with the land and would therefore be regarded as fringing reefs. This relation has usually been brought about, however, by small geographic changes, such as the drifting of the shore sands behind the outer reefs. The channel between the coral reefs and the shore is deepest between the Abrolhos and the Parcel das Paredes. It is there only eleven fathoms. For the most part the depth is considerably less, and too small to admit the entry of ordinary sailing vessels.

With the exceptions noted below the coral reefs of Brazil have no apparent connection with eruptive phenomena. There are probably incipient reefs about the volcanic island of Fernando de Noronha, and it is possible or even probable that the Rocas reefs are built upon an eruptive base. But the Rocas reef is two hundred and twenty-four kilometres from the Brazilian mainland, with a channel of over two thousand fathoms separating it from the barrier reefs of the coast. The island of Santo Aleixo, just south of Cape Santo Agostinho, is likewise eruptive, but it is only two or three kilometres from the shore, and therefore has no relation with the coral reefs other than that of the sedimentary rocks along the same coast. There are igneous rocks also in the Abrolhos Islands, but they are sheets and dikes in the rocks that form the group.

THE CHEMICAL COMPOSITION OF THE BRAZILIAN CORALS.

I have had analyses made of a few of the skeletons of living corals the results of which are given in table (A) on page 264.

All samples were washed with boiling distilled water to remove sea salt, and the complete removal was verified. The washed samples were dried, and of these the analyses were made. All the specimens contained considerable organic matter.

It should be noted that these analyses are of skeletons of polyps, the upper portions of which were living when the samples were collected. Samples were also taken of the dead reef rock at Ponta do Mangue, State of Alagôas, one hundred kilometres northeast of Maceio, and of this rock an analysis has been made with the results as given in table (B) on the next page.

If all the calcium present were there as carbonate, and the rest of the carbon dioxide as magnesium carbonate, it would be equivalent to

Carbonate of lime ($CaCO_3$)	82.19
Carbonate of magnesium ($MgCO_3$) . . .	12.98

It should be especially noted that the specimens of the reef rock represented by the last analyses were taken from an old reef that has long been dead.

(A.) Analyses of Brazilian Corals.

L. R. Lenox, Analyst.

Found.	I. *Heliastraea aperta* (Maceio).	II. *Porites branneri* (Rio Grande do Norte).	III. *Mussa hartii* (Maceio).	IV. *Porites verrilli* (Maceio).	V. *Symphyllia hartii* (Maceio)	VI. *Millepora brasiliensis* (Maceio).
Silica (SiO_2)	.05	.03	.12	.05	.08	.03
Oxides of Iron and Alumina (Al_2O_3, Fe_2O_3).	.07	.09	.20	.22	.08	.07
Lime (CaO)	54.41	54.29	54.13	52.33	54.30	53.41
Magnesia (MgO)	.24	.20	.26	.25	.21	.99
Sulphuric acid (SO_8)	.52	.54	not deter.	not deter.	not deter.	1.56
Probable Combinations.						
Silica (SiO_2)	.05	.03	.12	.05	.08	.03
Oxides of Iron and Alumina (Al_2O_3, Fe_2O_3)	.07	.09	.20	.22	.08	.07
Calcium carbonate ($CaCO_3$)	96.52	96.28	96.66	93.44	96.96	93.80
Magnesium carbonate ($MgCO_3$)	.50	.42	.54	.52	.44	2.08
Calcium sulphate	.88	.91	not deter.	not deter.	not deter.	2.14
Organic matter, Sodium chloride	not deter.	not deter.	not deter.	not deter.	not deter.	not deter.
Totals	98.02	97.73	97.52	94.23	97.56	98.12

(B.) Analysis of the Reef Rock of Ponta do Mangue, State of Alagôas, Brazil.

R. E. Swain, analyst.

	No. 1.	No. 2.
Calcium oxide (CaO)	46.01	46.03
Magnesia (MgO)	6.95	7.05
Iron (Fe_2O_3)	0.85	0.88
Alumina (Al_2O_8)	0.56	0.59
Sodium (Na)	trace	trace
Carbon dioxide (CO_2)	42.94	42.96
Silica (SiO_2)	1.27	1.29
Phosphoric anhydride (P_2O_5)	0.27	0.26
Chlorine (Cl)	0.31	0.28
Water (H_2O)	0.79	0.77
Total	99.95	100.11

The chief interest in these analyses lies in the difference in magnesium contents between the rock of the living coral and the old coral rock: excepting the Millepora none of the living corals contain more than a half of one per cent of magnesium carbonate, while the old rock contains nearly 13 per cent.

Evidently coral polyps secrete pure lime carbonate skeletons, and when a coral reef stands for a long period saturated with sea water, some of the lime of the coral mass is replaced by magnesium from the sea water, and a dolomite, or dolomitic limestone, is thus eventually produced.

It seems evident also that this process of dolomitization could only take place beneath the sea where magnesium water is available, and in material sufficiently porous to permit some circulation of sea water.

Since these results were obtained I have found that as long ago as 1846 Dana had analyses made of the skeletons of living corals, and that very little magnesia was found in them.[1]

In 1852 he reported an analysis by Silliman of "the coral limestone of the elevated coral island Matea" in which 38.07 per cent of carbonate of magnesia was found. These facts led Dana to infer that the lime carbonate had been replaced by magnesia.[2]

The results obtained from the Brazilian reefs agree very closely with those obtained by Dana for the Pacific corals except that the analysis of the older Brazilian coral rock was made of a rock still within the reach of the sea water, and in which dolomitization was apparently in process, while the analysis of the Pacific coral rock was made from materials far beyond the reach of the sea and in which dolomitization had evidently proceeded much further.

Another matter of interest in connection with the old reef rock is that the structure of the mass seems to be disappearing in proportion as the dolomitization takes place. In the fresh materials there is no difficulty in determining the forms of the organisms that have produced the rock, while the structure of the old reef rock is much obscured, and most of the organisms quite impossible of identification.

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[1] On the chemical composition of the calcareous corals. By B. Silliman, Jr. Amer. Journ. Sci., ser. 2, 1846, Vol. I., p. 189–199.

[2] James D. Dana. On coral reefs and islands. Amer. Journ. Sci., ser. 2, 1852, XIV., p. 82.

LIST OF THE CORALS OF THE COAST OF BRAZIL.

The following list is made up from the observations of the author and from all the known lists and descriptions of Brazilian reef corals. Following the name of each locality are given in parentheses the names of the authorities or collectors. Two other species are mentioned as having been found at the Lagôa de Camamú by Spix and Martius, but it has not been possible to identify them. The list does not include the deep-sea corals dredged off the coast by the "Challenger"[1] and other expeditions.

Most of the identifications have been made by Dr. Greeley, who was kindly assisted in doubtful cases by Dr. T. W. Vaughan. Professor Verrill's paper on Brazilian corals, published in the Transactions of the Connecticut Academy of Science, XI., was not seen until after this report was in type. That paper contains several varieties not mentioned in this list. It has not been possible to revise the list since seeing the paper of Professor Verrill.

CLASS ANTHOZOA.

1. *Astrangia solitaria* (?) Milne Edwards and Haime.[2]
2. *Phyllangia americana* Milne Edwards and Haime.

   These two forms were found on the sandstone reefs north of Pernambuco. The *Astrangia* was also found by Von Ihering at Bahia and at São Sebastião, State of São Paulo, and by Branner at Caravellas.
3. *Heliastraea* (*Orbicella*) *aperta* Verrill.

   Trans. Conn. Acad., Vol. I., part 2, page 356. Maceio coral reef (Greeley). Itaparica (Rathbun). Abrolhos (Hartt).
4. *Heliastraea* (*Orbicella*) *acropora* Linn.

   Bahia de Camamú (Spix and Martius).
5. *Heliastraea* (*Orbicella*) *cavernosa* Milne Edwards and Haime.

   Lagôa de Camamú, Bahia (Spix and Martius). It was also dredged in 30 fathoms off Barra Grande, Brazil. This is a West Indies species of reef coral. The station at which it was found is at about west longitude 34° 49′, south latitude 9° 7′, near the edge of the 100 fathom line.[3]

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[1] John J. Quelch. Report on the reef-corals collected by H. M. S. "Challenger" during the years 1873–1876. "Challenger" Reports, Zoölogy, Vol. XVI.; Th. Studer. Supplementary report on the Alcyonaria, Vol. XXXII., London, 1889.

[2] Dr. Vaughan says there are three species of *Astrangidae* on the coast of Brazil: *Astrangia*, similar to *A. solitaria* (Les.) Ver. 1864; a new species, *A. Rathbuni* Vaughan MS.; and *Phyllangia americana* Milne Edw. and Haime. (Porto Rican Corals, p. 299.)

[3] "Challenger" Reports, Zoölogy, XVI., 13.

6. *Favia gravida* Verrill.

   Trans. Conn. Acad., Vol. I., part 2, page 355. Rio Grande do Norte sandstone reef, Cape Bacoparý, Mamanguape, Goyanna (Greeley). Pernambuco sandstone reef (Hartt). Maceio coral reef (Greeley). Abrolhos and Cape Frio (Hartt). Itaparíca (Rathbun). Rio Formoso, Tamandaré, Santo Aleixo, Parcel das Paredes (Branner).

7. *Favia conferta* Verrill.

   Fernando de Noronha (Branner).[1]

8. *Favia ananas* Lamk.

   Fernando de Noronha (Ridley).

9. *Favia deformata* Milne Edwards and Haime.

   Fernando de Noronha (Ridley).

10. *Mussa harttii* Verrill.

    Trans. Conn. Acad., Vol. I., part 2, page 357. Maceio coral reef (Greeley). Abrolhos (Hartt). Candeias (Hartt). Rio Formoso, Parcel das Paredes (Branner). Itaparíca (Rathbun).

11. *Mussa verrillii* Rathbun.

    Fernando de Noronha (Branner).

12. *Symphyllia harttii* Verrill.

    Trans. Conn. Acad., Vol. I., part 2, page 358. Maceio coral reef (Greeley). Abrolhos and Lixa reefs (Hartt). São Sebastião, State of S. Paulo (H. Von Ihering). Itaparíca (Rathbun).

13. *Dichocoenia uva* Milne Edwards and Haime.

    Bahia de Camamú (Spix and Martius).

14. *Pectinia brasiliensis* Milne Edwards and Haime.

    Water-worn specimens were found by Mr. Branner at several places along the beach between Rio Manguába and Rio Camaragibe. It was also found at Bahia by Dr. Von Ihering.

15. *Agaricia agaricites ?* Milne Edwards and Haime.

    Maceio coral reef (Greeley). Abrolhos (Hartt). Parcel das Paredes, Santo Aleixo, Rio Formoso (Branner).

16. *Siderastraea stellata* Verrill.

    Itaparíca (Rathbun). Santo Aleixo (Branner).

17. *Porites verrilli* Rehberg.

    Trans. Conn. Acad., Vol. I., part 2, page 358, as *P. solida*. Rio Grande do Norte sandstone reef, Cape Bacoparý, Mamanguape, Goyanna (Greeley). Pernambuco sandstone reefs (Hartt, Branner). Maceio coral reef (Greeley). Abrolhos and Lixa reefs (Hartt). Candeias (Hartt). Tamandaré, Rio Formoso, Maria Farinha, Parahyba do Norte (Branner).

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[1] In Verrill's late paper on Brazilian corals, published in the Trans. Conn. Acad. Sci., XI., *Maeandra conferta* is reported to have been collected at Fernando de Noronha by Hartt. The corals sent Verrill from Fernando were collected by the writer in 1876. Hartt never visited that island.

18. *Porites branneri* Rathbun.
    Proc. U. S. Nat. Mus., Vol. X., 1887, p. 355–356. Parahyba do Norte (Branner). Candeias (Hartt). Rio Grande do Norte sandstone reef, Maceio coral reef (Greeley).
19. *Gorgonia quercifolia* Milne Edwards and Haime.
    Fernando de Noronha (Branner).
20. *Gorgonia*, sp. ?
    Fernando de Noronha (Branner).
21. *Hymenogorgia quercifolia* Milne Edwards and Haime.
    Cape Frio to Pernambuco (Hartt).
22. *Eunicea humilis* Milne Edwards and Haime.
    Abrolhos, Porto Seguro (Hartt).
23. *Eunicea sulphurea* Ehr.
    Parahyba do Norte (Branner).
24. *Eunicia castelnaudi* Milne Edwards and Haime.
    Bahia (Castlenau).
25. *Plexaurella dicholoma* Köll.
    Abrolhos (Hartt). Rio Formoso, Parahyba do Norte (Branner).
26. *Plexaurella anceps ?* Köll.
    Abrolhos (Hartt).

Class HYDROZOA.

27. *Millepora braziliensis* Verrill.
    Trans. Conn. Acad., Vol. I., part 2, page 363. Maceio coral reef (Hartt, Greeley). Abrolhos and Pernambuco (Hartt). Itaparíca (Rathbun). Fernando de Noronha, Rio Formoso, Parahyba do Norte, Parcel das Paredes (Branner).
28. *Millepora alcicornis* Linn.
    Trans. Conn. Acad., Vol. I., part 2, page 363. Candeias (Hartt). Pernambuco sandstone reef (Hartt). Maceio (Greeley). Bahia (Von Ihering). Rio Formoso (Branner).

Notes on the Corals collected on the Northeast Coast of Brazil. — *By Arthur W. Greeley.*

The corals collected by the expedition along the coast of Brazil in June and July of 1899 may be divided into two groups, — first, those taken on the sandstone reefs along the northern part of the coast from Pernambuco to Natal, and second, the collection made on the coral reef of Maceio, Alagôas. The collecting on the sandstone reefs was very hastily done because of the large extent of coast-line to be covered, and the few species of coral obtained do not represent all the corals to be found on the stone reefs. Three weeks were spent on the Maceio reef, however, and the collection is probably complete for that locality.

On the sandstone reefs four species of corals were obtained, *Porites verrilli*, *Porites branneri*, *Favia gravida*, and *Millepora alcicornis*. Although two of these, *Porites verrilli* and *Favia gravida*, are very common, growing abundantly on every reef visited, the corals at no place form any considerable part of the stone reefs, but exist only in small, isolated masses. The other two species are not at all abundant, *Porites branneri* being obtained only on the Rio Grande do Norte reef, and *Millepora alcicornis* only at Pernambuco.

The outer edge of the sandstone reefs slopes gradually toward the sea, and is everywhere cut up by the waves, forming pools and caverns that are lined with encrusting anemones, ascidians, etc. It would seem that these sheltered pools, continually washed as they are by the fresh water of the outside of the reef, ought to afford splendid locations for the growth of these corals. On the contrary, they do not grow here at all, but are found chiefly on the inner edge of the reef, even in places where the coral heads are nearly covered by the silt and sand that is washed by the river currents against the inside of the reefs. Small masses of coral are scattered over the top of the reefs in the shallow pools that are always full of water, but the largest heads are always found along the extreme inner edge. The abundant growths of encrusting anemones and barnacles on the exposed portions of the sandstone afford a considerable protection from the never-ceasing pounding of the waves, but the corals scattered in small, isolated masses are of little or no importance in the formation or preservation of these wonderful sandstone reefs.

Porites verrilli is by far the hardiest and most abundant coral on this part of the coast, and thrives wherever there is a suitable ledge of rock upon which to grow. It forms remarkably round, even, perfect heads, never attaining a greater size than a foot in diameter on the sandstone reefs, and usually only a few inches. It was found commonly on all the reefs visited, and its hardiness is well shown by the apparent ease with which it adapts itself to all sorts of unfavorable conditions, growing high up on the reef, sometimes entirely exposed at low tide, and sometimes buried in the mud on the inside of the reef. The rock of this species is remarkably solid and firm, and is much thicker and more lasting than that of any other species.

Growing with *Porites verrilli*, though not so common, is *Favia gravida*. These two species form nine tenths of all the coral life on the sandstone reefs, and follow each other in distribution, although *Favia gravida* is not so hardy, and does not thrive so well in the muddy water along the inside of the reef. Its heads are very small, rarely more than two or three inches in diameter, and not more than an inch or so in thickness. This species varies considerably in the character of the walls between the cells. Typically they are thin and ungrooved, but in a few small specimens from the Mamanguape and Rio Grande do Norte reefs the walls were thick and decidedly concave.

Porites branneri is a rare coral and was found by the expedition only on the Rio Grande do Norte stone reef at Natal. One large head six inches in diameter, bluntly conical in shape and irregularly lobed, was collected. It is of a deep brown color in life. The cells resemble very much those of *Porites verrilli* in form, but they are smaller, and the texture of the rock is much more porous.

Millepora alcicornis was the only Millepore found on the sandstone reefs, and this one was observed in only one place, between two portions of the Pernambuco reef in about three feet of water at low tide. It formed here a clump a foot or so high, with a few smaller masses growing about it.

The Maceio coral reef. — The only true coral reef visited by the writer was the Maceio reef (see Fig. 94, p. 166), located about one hundred and fifty miles south of Pernambuco, off the town of Maceio, State of Alagôas. The reef is a splendid example of the great barrier reefs found along the Brazilian coast. The corals are very abundant, growing actively along the outer edge, and because of its easy accessibility from the shore, the reef is a good one for study. It is about three miles long, fully two thirds of a mile wide at its broadest part, and the whole of its upper surface is exposed at the lowest tides of each month. The reef is broadest at its northern end, where it joins a small point that forms the northern boundary of the Bay of Maceio. Here the reef is very firm and even, and it is possible to walk outward over two thirds of a mile of solid coral rock almost without any breaks. This part of the reef is apparently the oldest, and contains very few growing corals. From this point the reef runs nearly south at a distance of about half a mile from the shore, and becomes very irregular at the lower end, forming several small fragments of coral rock, one lying inside the other. This broken part of the reef abounds in growing corals along the narrow channels between the different sections of the reef, and the rock is much less solid, containing many pools and caverns that communicate with the outside, and all these channels are covered with corals of one kind or another. The coral rock formed at first is extremely irregular, existing in narrow ridges and ledges enclosing these hollow spaces in the reef; but as the growth continues the firmer corals gradually fill up these spaces so that the inner and older portions of the reef are comparatively smooth and solid. The inner edge of the reef consists of a perpendicular wall not more than five or six feet deep and usually much less, but the outer edge slopes gradually toward the sea for twenty feet or more, and then plunges directly downward as a sheer wall to a depth of twenty-five or thirty feet. This extreme outer edge at the top of the perpendicular wall is covered by two feet of water at low tide, and it is here that the corals grow in the greatest profusion along the whole face of the seaward wall and as high up as the tides will allow.

Sand has been constantly accumulating inside the reef so that the inner bay is not more than ten feet deep at any point. There are two or three isolated portions of the reef in this bay that have been nearly covered up by the sand and contain only dead coral rock.

The reef is everywhere covered by a solid layer of coralline rock. This coralline follows the corals wherever they grow, extending right up to the fleshy part of every coral head. On the older portions of the reef it adds the upper smooth layer, several inches in thickness, that cements together the loose coral rock and makes it lasting. Its importance as a protection to the reef can hardly be overestimated.

In some places there are elevated spots on the reef formed wholly of encrusting masses of worm tubes. These exist often in the most exposed positions, and form layers of great durability, although they are not of much importance to the reef because of their limited growth. The extreme outer edge of the reef where it is exposed to the full force of the breakers is carpeted by small encrusting anemones that are remarkably tenacious in their hold on the rocks, and must save these portions of the reef from much of the wear and tear of the waves. This part of the reef is greatly eaten away, however, by the common rock-boring sea-urchin, *Echinometra subangularis*, that is very abundant both here and on the sandstone reefs.

The general surface of the whole reef is quite even, and is exposed nearly two feet at extreme low tide. This exposed portion is composed almost entirely of coralline rock and various encrusting layers of worm tubes, etc. At several points near the northern and oldest part of the reef, however, there is solid coral rock well above the low-water mark, which seems to show that the oldest portions of the reef at least have once been considerably higher than their present level. One of these elevated portions consists of a solid mass of *Millepore* rock rising at least eight feet above the general surface of the reef, and is exposed even at high tide. This mass of rock is shaped like a pyramid, fifteen feet broad at the base, much honeycombed out by the waves.[1] At another part near by I found an extensive area of *Porites* rock nearly two feet above the level of low tide.

Porites verrilli is at Maceio, as at every other place where we collected, the most abundant coral, and is by far the most important structural coral of the reef. It grows everywhere, even on the sand-covered inner edges of the reef, where no other coral can live except *Favia conferta.* Notwithstanding the abundance of this species, it grows only in small isolated heads, and in no place could I find large masses of *Porites* growing in such a way as to form any considerable addition to the reef. At one time it must have grown in huge heads all over the reef, for the older portions are nearly solid *Porites* rock, which can readily be seen wherever the reef has been excavated for lime. So while the greater part of the reef has been built up by this species in former times, for some reason it has been crowded out of the growing part of the reef, and is now scattered everywhere in small isolated masses with *Favia conferta.* This coral forms extremely solid and lasting rock, though it is not so dense and durable as that of the *Millepores,* nor so hard and tough as the rock of the *Orbicella aperta.*

Porites branneri was found in only one place, growing in small heads, and appears to be rare here as elsewhere.

Favia gravida is scattered all over the reef with *Porites verrilli* in small heads which form no thick layers of coral rock. Its distribution on this coral reef agrees exactly with what was already observed on the sandstone reefs.

Millepora alcicornis and *Millepora braziliensis* were found in great numbers, and the former was, next to *Porites verrilli*, the most important structural coral obtained, forming with the *Porites* the greater part of the old reef. *Millepora alcicornis* lives on the extreme outer edge of the reef in the heavy breakers where few other corals grow. In these exposed places it thrives, growing either in huge erect clusters on submerged bases of rock, or in overhanging masses many feet in extent on the extreme outer edge of the main reef. In these the corals grow either outward horizontally or downward from the under surface of these overhanging ledges. In these single clusters all variations from the bluntly lobed to the slenderly pointed or fenestrated forms, until recently known as distinct varieties, were found, showing clearly that these are all simply different phases of this highly variable species. Much of these exposed portions of the reef seems to be solid *Millepore* rock, which is certainly being constantly added to by the rapid growth of this species at the present time. This *Millepore* rock is the most dense and durable of all, though it is extremely brittle, and, because of its mode of growth, is more easily broken than that of either *Porites verrilli* or *Orbicella aperta.*

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[1] This is an uptilted block that has been undermined by the waves. See pages 160 and 161 of this report. — J. C. B.

Millepora braziliensis grows all over the reef, but in small, isolated heads that add but little to the reef structure.

Orbicella aperta grows in regular heads that are sometimes two feet or more in diameter, and with an even greater depth of clean, unbroken rock, which is very tough and tenacious. This species would be a very important structural coral if it were more abundant, but it grows only in isolated masses which add comparatively little to the reef. It is found in the more sheltered places of the outer edge of the reef, and forms beautiful, conspicuous heads, because of the large cells and prominence of the polyps that look very much like small, encrusting anemones. The rock is porous but remarkably tough and durable.

Mussa harttii is the most striking coral of the Maceio reef. It completely lines the borders of the sheltered lagoons that are constantly filled with the fresh water of the outside. It is a densely branching species forming huge clumps of nearly a solid mass of short thick stems. These clumps rise to a height of ten or fifteen feet in the sheltered coves, but are usually only a foot or so high and as broad along the outer edge of the reef. These smaller clusters grow in the greatest profusion wherever the water is clear and the force of the waves is not too great. The thick stems are white surmounted by polyps of a brilliant lavender hue, that are extremely showy because of their large size and bright colors. The stems are very fragile, however, and this species adds to the reef by the accumulation of its broken fragments. After a time the clusters become too heavy for the weak stems, and the waves play havoc with the whole mass, scattering the branches all over the reef. Some of the best collecting of the whole reef is to be had in these *Mussa* heads, which harbor an immense variety of crustaceans, echinoderms, worms, etc.

Symphyllia harttii grows in the same locations as its near relative *Mussa harttii*, and resembles it very strikingly in appearance. The color and size of the polyps are about the same as those of *Mussa*, but *Symphyllia* grows in low solid heads, while *Mussa* forms branching clusters. *Symphyllia* is also very much less abundant than *Mussa*.[1]

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[1] Dr. T. W. Vaughan, to whom I am indebted for corrections in the nomenclature, tells me that *Symphyllia harttii* is, as Verrill at first suspected, only a growth form of *Mussa harttii*. J. C. B.

A species of *Agaricia* was found growing plentifully in the *Mussa* clusters. The polyps are of a beautiful brownish-red color with green centres.

This whole Maceio region is a very interesting one, and deserves more thorough investigation. North of this main reef just described there are many smaller patches of coral rock that may contain some of the other Brazilian corals described from Bahia and the Abrolhos by Verrill and Rathbun. If the collection described in this paper is complete, it is a remarkable fact that the range of a number of the corals so common in the south should end abruptly in the region of Bahia.

Résumé of Conclusions regarding the Coral Reefs.

The coral reefs of Brazil extend along the coast from the Abrolhos Islands in south latitude 18° nearly to the mouth of the Amazon River. The reefs, however, are not continuous, but are broken by many and large gaps. The only reefs well off the coast are on the Rocas Island in south latitude 3° 51′, west longitude 33° 48′, and 225 kilometres from the mainland. The reefs of the coast are both barrier and fringing reefs. They are usually narrow, — from ten to fifty metres in width; the widest are the barrier reefs, some of which are about thirty kilometres in width. Most of the near-shore reefs are quite thin, probably not exceeding a thickness of ten metres; the reefs that grow further out are thicker, and it is possible that some of the barrier reefs, like those of the Abrolhos group and of the Cape St. Roque group, have a maximum thickness of a hundred metres at their outer edges.

There were coral reefs on the Brazilian coast during Cretaceous times and also during Eocene and Pliocene times. The coral reefs may, therefore, be regarded as having survived since the Pliocene, at least. The reef corals are found both beneath and on top of the stone reefs with which they are contemporaneous. It is highly probable that some of the coral reefs of the coast grow upon and conceal stone reefs. The coral reefs have no connection with eruptive phenomena, with the possible exception of those of the Rocas, which are two hundred and twenty-five kilometres from the mainland.

Many of the Brazilian coral reefs, having reached the upward limit of growth, are now dead and are growing only laterally. This is true of both the large barrier reefs and of the fringing in-shore reefs.

The coral polyp fauna of Brazil contains twenty-eight known species.

This fauna is more closely related to that of the West Indies than to any other now known.

The dead coral reef rock is being changed to dolomite by the replacement of a part of the calcium by magnesium from the sea water.

No recent coral reefs elevated above tide-level are known on the coast of Brazil. There are, however, satisfactory evidences of a late elevation of the coast amounting to about two metres. At many places dead coral reefs are buried beneath sands and other mechanical accumulations brought down from the land.

The coral reefs have been an important protective and constructive factor in controlling the outlines of the Brazilian coast. Some of the small harbors of the coast are formed by coral reefs: such are Maceio and Tamandaré. The sand beaches and spits have also, under the protection of the reefs, extended themselves seaward, and even encroached upon and buried some of the coral reefs themselves.

EXPLANATION OF THE PLATES.

PLATE 1.

Northeast coast of Brazil, showing the locations of stone and coral reefs and the configuration of the ocean's floor off the coast from Bahia to Aracatí. See page 183.

PLATE 2.

Map of the stone reef at Pernambuco, made by Harold Havens, July, 1899. See page 60.

PLATE 3.

Santa Cruz Bay, part of Hydrographic Chart 484, with additions. See page 95.

PLATE 4.

Map of the Bay of Bahia: a part of Hydrographic Chart No. 1522. Most of the soundings given on the original are omitted. See page 128.

PLATE 5.

Topographic map of the Brazilian coast about Santos, showing how the coastal mountains have been submerged, leaving their peaks as islands or as hills in a swampy region. (Reduced from the São Paulo sheet of the Commissão Geologica de S. Paulo.) See pages 128 and 129.

PLATE 6.

Part of Hydrographic Chart 481, showing the reefs at Cape St. Roque. See page 228.

PLATE 7.

Part of the Hydrographic Chart of the mouth of the Rio Parahyba do Norte, showing the coral reef and its relation to the coast. See page 232.

PLATE 8.

The reefs from Santa Cruz to Comoxatíba, State of Bahia. From the Hydrographic Chart; with additions showing the stone and coral reefs. See page 251.

PLATE 9.

Part of the Hydrographic Chart, showing the Lixa, Parcel das Paredes, and Abrolhos coral reefs. See pages 251–257.

PLATE 10.

Abrolhos Islands: a part of the Hydrographic Chart. The submarine contours are drawn in from the soundings. See pages 256–258.

PLATE 11.

The Tertiary (?) cliffs at Barreira do Camaragíbe, State of Alagôas. At the base of the bluffs the rocks are buff and gray; the same beds higher up are brightly colored. Photograph taken from ledge exposed at low tide. See page 19.

PLATE 12.

Tertiary (?) sandstones and shales a mile south of Barreira do Camaragíbe. The upper parts of these beds are highly colored: the lower parts are of neutral tints. See page 19.

PLATE 13.

The beach at Camaxo, on the coast of Alagôas, where the basal Tertiary (?) conglomerates contain large granite boulders. Looking S. 48° W. São Bento in the distance.

PLATE 14.

Ruinas de Palmyra, near Olinda, State of Pernambuco. See page 22.

PLATE 15.

Cape Branco, coast of Parahyba do Norte. The cape bears S. 50° W. See page 23.

PLATE 16.

The sandstone reef at Natal, Rio Grande do Norte, looking northward from the lighthouse on the reef. See pages 35–39.

PLATE 17.

Looking south from the anchorage behind the reef at Natal, Rio Grande do Norte. See pages 35–39.

PLATE **18.**

The dunes south of Rio Grande do Norte, near the mouth of the river. See pages 35 and 121.

PLATE **19.**

The dunes north of the mouth of the river at Rio Grande do Norte. This is a characteristic bit of the coast north of Natal. See page 122.

PLATE **20 a.**

The northern end of the stone reef at Natal, taken from the anchorage behind the reef. Part of panorama with Plate No. **20 b**. See pages 35–39.

PLATE **20 b.**

The stone reef at Rio Grande do Norte, from the anchorage behind the reef. The fort (Fortaleza dos Reis Mages) is built upon the reef. This plate forms a panorama with Plate **20 a**. See pages 35–39.

PLATE **21.**

The southern part of the Cunhahú stone reef, looking north from the dunes. See pages 40–45.

PLATE **22.**

Looking south over the north end of the Cunhahú stone reef toward Bahia Formosa. See pages 40–45.

PLATE **23.**

The north end of the Cunhahú stone reef at low tide where it joins the land. See pages 40–45.

PLATE **24.**

Looking northward toward Ponta da Pipa and the north end of the Sibaúma reef. See pages 40–45.

PLATE **25.**

Boulder-like masses of sand held together by worms; on the beach one mile north of Bahia Formosa. See pages 44 and 45.

PLATE **26 a.**

The south end of the Traição sandstone reef, at low tide. (No. **26 b** joins this on the right to form panorama.) See pages 45–47.

PLATE **26 b**.

Part of the Traição sandstone reef. (No. **26 c** joins this on the right, and **26 a** joins it on the left.) See pages 45–47.

PLATE **26 c**.

Part of the Traição reef panorama. (No. **26 d** joins this on the right, and **26 b** joins it on the left.) See pages 45–47.

PLATE **26 d**.

Part of the Traição reef panorama. (No. **26 e** joins this on the right, and **26 c** on the left.) See pages 45–47.

PLATE **26 e**.

Part of the Traição reef panorama. (No. **26 f** joins this on the right, and **26 d** on the left.) See pages 45–47.

PLATE **26 f**.

Part of the panorama of the Traição reef. (No. **26 g** joins this on the right, and **26 e** on the left.) See pages 45–47.

PLATE **26 g**.

The northern end of the Traição sandstone reef. (No. **26 f** joins this on the left.) See pages 45–47.

PLATE **27 a**.

The village of Traição on the Bay of Traição, behind a stone reef. (This forms a panorama with No. **27 b** on the right.) See pages 45–47.

PLATE **27 b**.

The village of Traição in a grove of coco palms. Fish traps in the foreground. Join this to No. **27 a** for panorama. See pages 45–47.

PLATE **28**.

The sand neck separating Traição Bay from Lagoa de Sinimbú. This neck is occasionally encroached upon by the sea. See page 133.

PLATE **29 a**.

Traição Bay and the northern end of Traição stone reef. (No. **29 b** joins this on the right to form panorama.) See pages 133 and 134.

PLATE 29 b.

The sand neck between Traição Bay and Lagoa de Sinimbú. Part of the Traição Bay panorama. Plate 29 a joins this on the left.

PLATE 30.

The neck of sand between Traição Bay on the right and Lagoa de Sinimbú on the left, looking northward. See pages 133 and 134.

PLATE 31.

The northern end of Mamanguápe stone reef seen from behind the reef at low tide. See pages 47–55.

PLATE 32.

Looking south along the Mamanguápe sandstone reef at low tide. See pages 47–55.

PLATE 33.

Looking north along the Mamanguápe stone reef; the tide not all out. See pages 47–55.

PLATE 34.

Looking southward, and showing the branching and bending of the Mamanguápe sandstone reef. See page 48.

PLATE 35.

A break in the Mamanguápe reef caused by undermining. The blocks in the gap are covered with seaweeds. See pages 47–55.

PLATE 36.

Looking northward along the seaward side of the Mamanguápe sandstone reef. See pages 47–55.

PLATE 37.

Looking northward along the outer side of the Mamanguápe reef at low tide. See pages 47–55.

PLATE 38.

Along the landward side of the Mamanguápe reef, showing blocks broken by the surf from the outer face and thrown across the reef. The curving of the reef is also shown. See pages 47–55.

PLATE 39.

The vertical outer face of the Mamanguápe reef, looking southward at low tide. See pages 47–55.

PLATE 40.

Blocks of compact sandstone thrown by the surf across the Mamanguápe reef. The inner reef crosses the middle of the background. See page 50.

PLATE 41.

A characteristic bit of surface etching on the Mamanguápe reef. See page 52.

PLATE 42.

The eroded surface of the Mamanguápe reef partly covered with barnacles. See page 53.

PLATE 43.

Sea-urchin holes in the seaward face of the Mamanguápe reef. See page 53.

PLATE 44.

Looking southward near the southern end of the Mamanguápe reef. The Mirimirí cliffs are visible in the distance. See pages 47–55.

PLATE 45.

Mamanguápe Point, and the southern end of the inner reef seen from the outer reef, looking westward. See page 55.

PLATE 46.

The sand plains at Cabedello, Parahyba do Norte. Photograph by Mr. Sumner. See pages 232–235.

PLATE 47.

The Pernambuco stone reef. Photograph taken in 1876 by the Commissão Geologica. See pages 60–67.

PLATE 48.

The Pernambuco reef taken from the old Dutch fort. See pages 60–67.

PLATE 49.

Surface of Pernambuco reef. Photograph taken in 1876. See pages 60–67.

PLATE **50**.

Pernambuco reef rock bored by sea-urchins. See pages 60–67.

PLATE **51**.

The sandstone reef on the beach north of Gaibú, seen from above the old Dutch fort at Gaibú. See pages 69–71.

PLATE **52 a**.

The sandstone reef running south from Cabo Santo Agostinho. (No. **52 b** forms a panorama with this.) See pages 71–78.

PLATE **52 b**.

Part of the panorama of the sandstone reef south of Cabo Santo Agostinho. This view joins No. **52 a** on the right. See pages 71–78.

PLATE **53**.

A part of the Cabo Santo Agostinho reef near its southern end at Camboa. The sand flat between the reef and the shore is uncovered at low tide. See pages 71–78.

PLATE **54**.

The stone reef south of Cabo Santo Agostinho seen from near its southern end and from the rear at low tide. There is a long pool of water on top of the reef at this place. See pages 71–78.

PLATE **55**.

The sandstone reef near the lighthouse at Bahia. Photograph taken in 1876. In 1899 these vast rocks had all been quarried out. See pages 93–95.

PLATE **56**.

The north end of the sandstone reef at Santa Cruz, State of Bahia. See page 95.

PLATE **57**.

The stone reef at Porto Seguro, State of Bahia. Photograph taken from a steamer inside of the reef at high tide. See pages 97–99.

PLATE **58**.

Copy of the map of Pernambuco and the reef published by Caspar Barlaeus in 1647. See page 116.

PLATE **59**.

View of the stone reef at Pernambuco, drawn by F. Post in 1645 and published by Barlaeus in 1647. See page 202.

PLATE **60**.

Map of the stone reef at Cabo Santo Agostinho, published by Caspar Barlaeus in 1647. (Rerum per octennium in Brasilia op. p. 140.) See page 71.

PLATE **61**.

Map of the stone reef at Natal, Rio Grande do Norte, published by Barlaeus in 1647. Compare Fig. 13, page 37.

PLATE **62**.

Fortaleza dos Reis Magos — the fort on the sandstone reef at Natal, Rio Grande do Norte. Probably drawn by F. Post about 1645 and published by Barlaeus in 1647. Compare Plates **20 a** and **20 b**.

PLATE **63**.

Tertiary(?) bluffs at Bahia Formosa, State of Rio Grande do Norte. The sloping upper beds are old sand dunes. See page 122.

PLATE **64**.

Tertiary (?) bluff at Pipa, with brown sand on top of it. Looking westward from the anchorage. Bluff about two hundred feet high. See also Plate **63**.

PLATE **65**.

Characteristic topography of the Pernambuco coastal sand plain near Boa Viagem. See pages 137 and 138.

PLATE **66**.

Tertiary bluff at Santa Cruz, State of Bahia. See pages 141–142.

PLATE **67**.

The gorge of the Rio São Francisco, at Piranhas. See page 143.

PLATE **68**.

An elevated beach at Ponta de Areia, Bay of Bahia, two kilometres north of São Thomé. See page 150.

PLATE 69.

The terrace at Opába, Boa Vista Fazenda, just north of Ilheos, State of Bahia. See pages 154 and 155.

PLATE 70.

The terrace at Vellosa, about two kilometres north of Ilheos, State of Bahia. See page 155.

PLATE 71.

The penedo, a peak of exfoliated granite at Victoria, State of Espirito Santo. See page 158.

PLATE 72.

A line of pits on the granite peak at Victoria, Espirito Santo, showing recent elevation of the coast. Photograph taken from a passing steamer. See page 158.

PLATE 73.

Sea-urchin burrows in blocks of trachyte on the beach three hundred metres northwest of Pedras Pretas point, coast of Pernambuco. See page 159.

PLATE 74.

Young mangroves, showing how the roots spread through the water; Affogados, near Pernambuco. See page 167.

PLATE 75.

General view of the edge of a mangrove swamp, showing the close-set plants. See page 167.

PLATE 76.

Coral reefs, three kilometres south of São Miguel, State of Alagôas. There is one coral reef on the horizon, one in the middle background, and one in the foreground overlapped by beach sands. See page 242.

PLATE 77.

The Maccio coral reefs seen from the beach at Jaraguá, State of Alagôas ; low tide. See pages 270–274.

PLATE 78.

The Itaparíca coral reef south of Bahia. Photograph made in 1875 by the Commissão Geologica da Brazil. See pages 246–249.

PLATE **79**.

Burrowed dead coral reef, Itaparíca, State of Bahia.

PLATE **80**.

Barnacles on the surface of a dead coral reef, Itaparíca, Bahia.

PLATE **81** a.

The Lixa coral reef, off the Caravellas coast, State of Bahia. The photographs were taken shortly after the reef was fully uncovered, looking across the reef at its widest part. (No. **81 b** joins this on the right to form a panorama.) See pages 251–256.

PLATE **81** b.

For title see No. **81 a**, which joins this on the left. See pages 251–256.

PLATE **82** a.

View on the Lixa coral reef at low tide, looking N. 80° W. toward the land.

PLATE **82** b.

Lixa coral reef near the northern end, looking N. 25° W. at low tide. See pages 251–256.

PLATE **82** c.

Lixa coral reef at low tide, looking S. 64° W. The pools are only a few inches deep. (No. **82 d** joins this on the right for a panorama.) See pages 251–256.

PLATE **82** d.

For title see No. **82 c**. This overlaps No. **82 c** somewhat on the right. See pages 251–256.

PLATE **83** a.

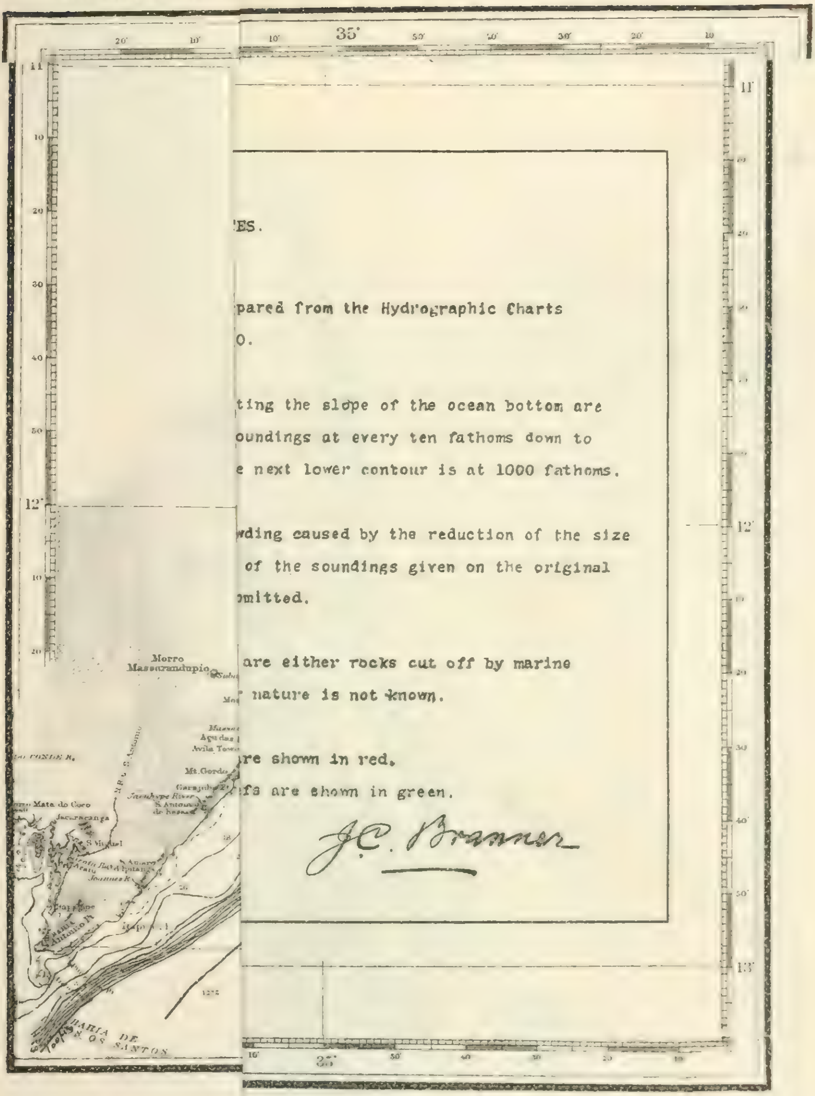
Panorama of the coast north of Maceio, seen from the lighthouse on the hills above the city. (Two others, **83 b** and **83 c**, join this on the right.) See pages 130 and 164.

PLATE **83** b.

The coast north of Maceio. Panorama with Nos. **83 a** and **83 c**. See pages 130 and 164.

PLATE **83** c.

The coast north of Maceio. Panorama with Nos. **83 a** and **83 b**. See pages 130 and 164.


35'
20'
10'
10'
50'
40'
30'
20'
10
11°
12°
13°
Morro
Massarandupio
Subaúma
Mo
Massar
Agua das
Avila Tower
CONDE R.
R. S. Antonio
Mt. Gordo
Garajuba Pt.
Jacuhype River
S. Antonio de Jesus
Mata do Coco
Jacaracanga
S. Miguel
Arato
Amaro
Itapuan
Joannes R.
Itaparica
S. Antonio R.
Itapoan
1275
BAHIA DE TODOS OS SANTOS
16'
35'
50'
40'
30'
20'
10

ES.

pared from the Hydrographic Charts
O.

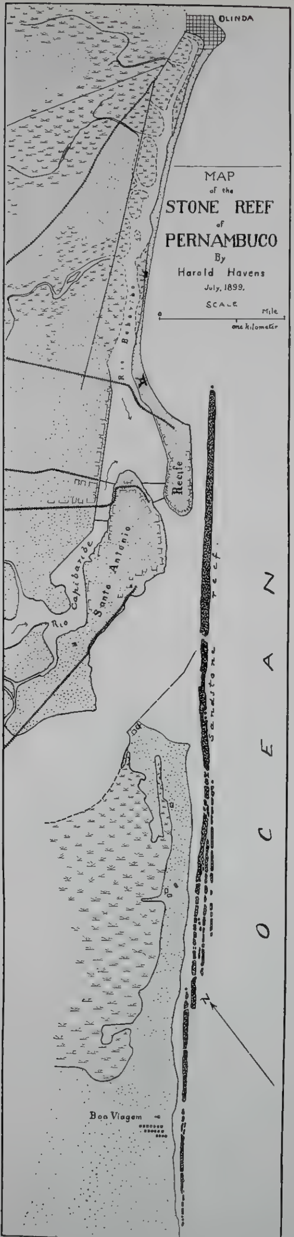
ting the slope of the ocean bottom are
oundings at every ten fathoms down to
e next lower contour is at 1000 fathoms.

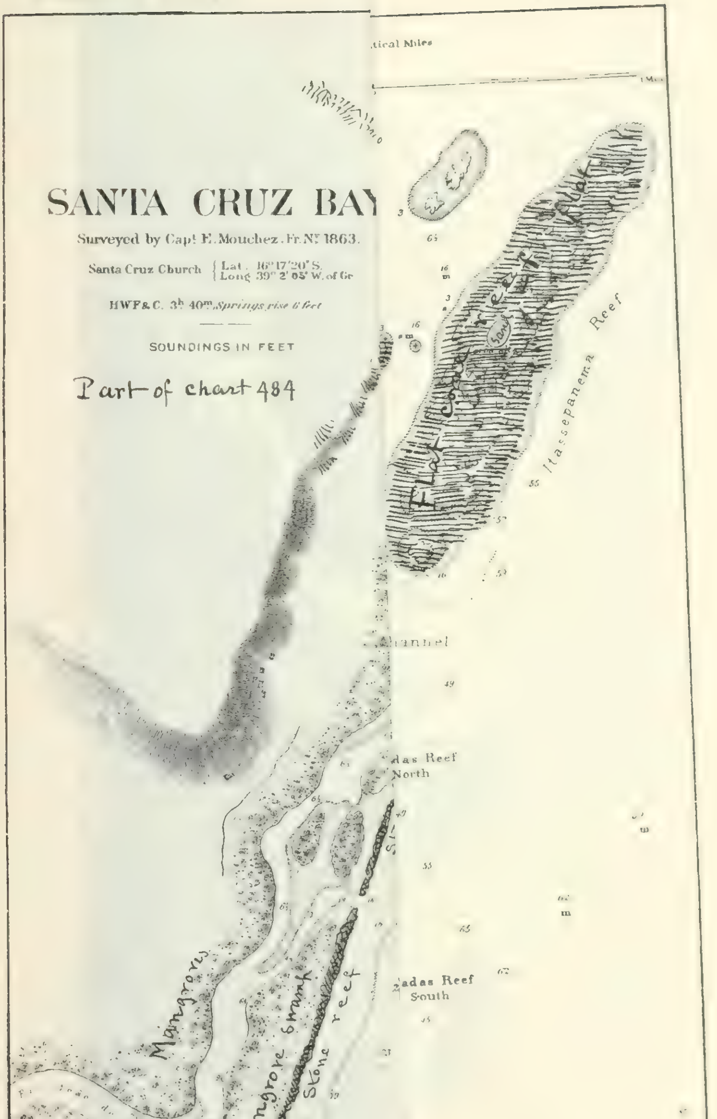
wding caused by the reduction of the size
of the soundings given on the original
omitted.

are either rocks cut off by marine
nature is not ~~known~~ known.

re shown in red.
fs are shown in green.

J.C. Branner


OLINDA
MAP
of the
STONE REEF
of
PERNAMBUCO
By
Harold Havens
July, 1899.
SCALE
0
Mile
one kilometer
Rio Beberibe
Recife
Rio Capibaribe
Santo Antonio
Sandstone reef.
OCEAN
N
Boa Viagem



SANTA CRUZ BAY

Surveyed by Capt E. Mouchez. Fr. N. 1863.

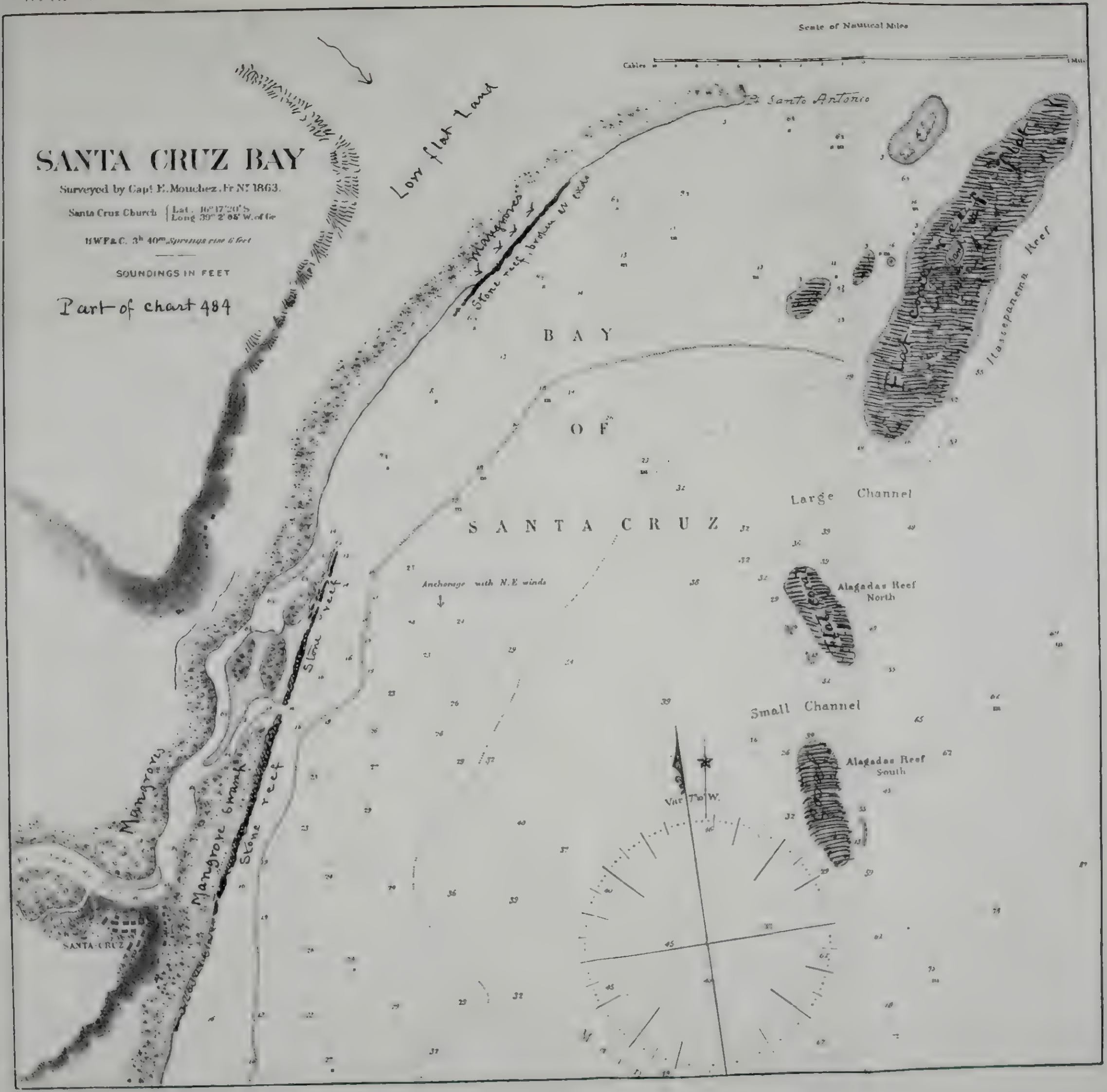
Santa Cruz Church { Lat. 16° 17' 20" S. Long. 39° 2' 05" W. of Gr

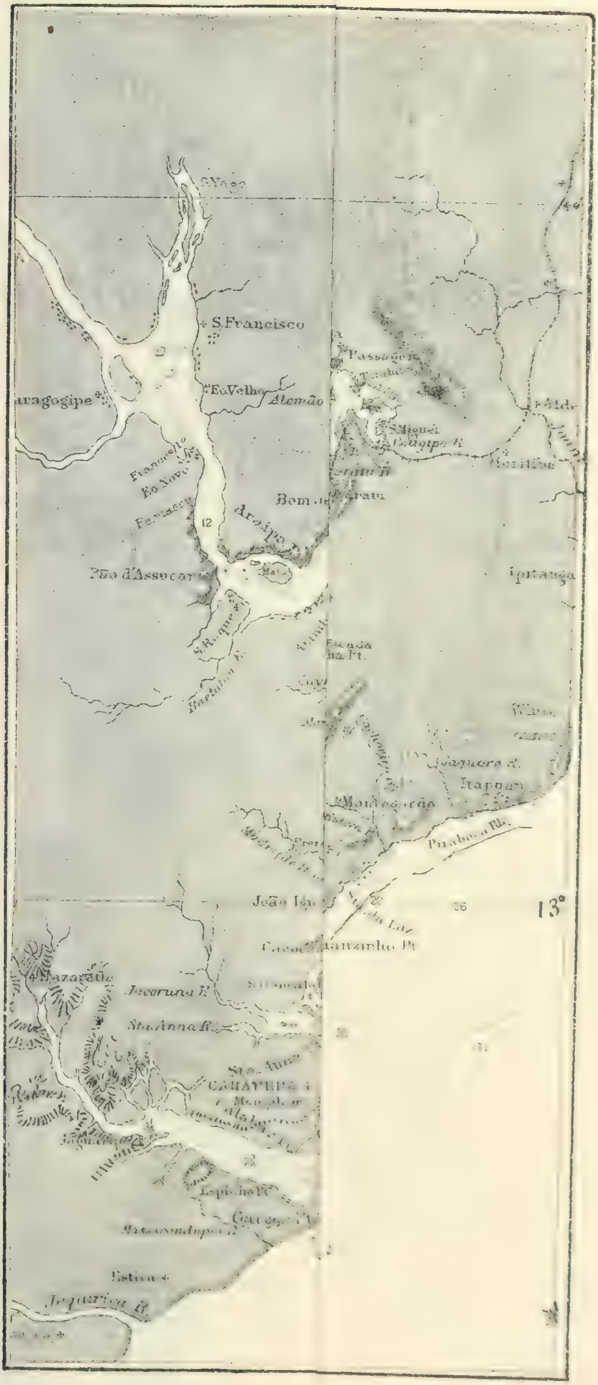
HWF&C. 3h 40m, Springs rise 6 feet

SOUNDINGS IN FEET

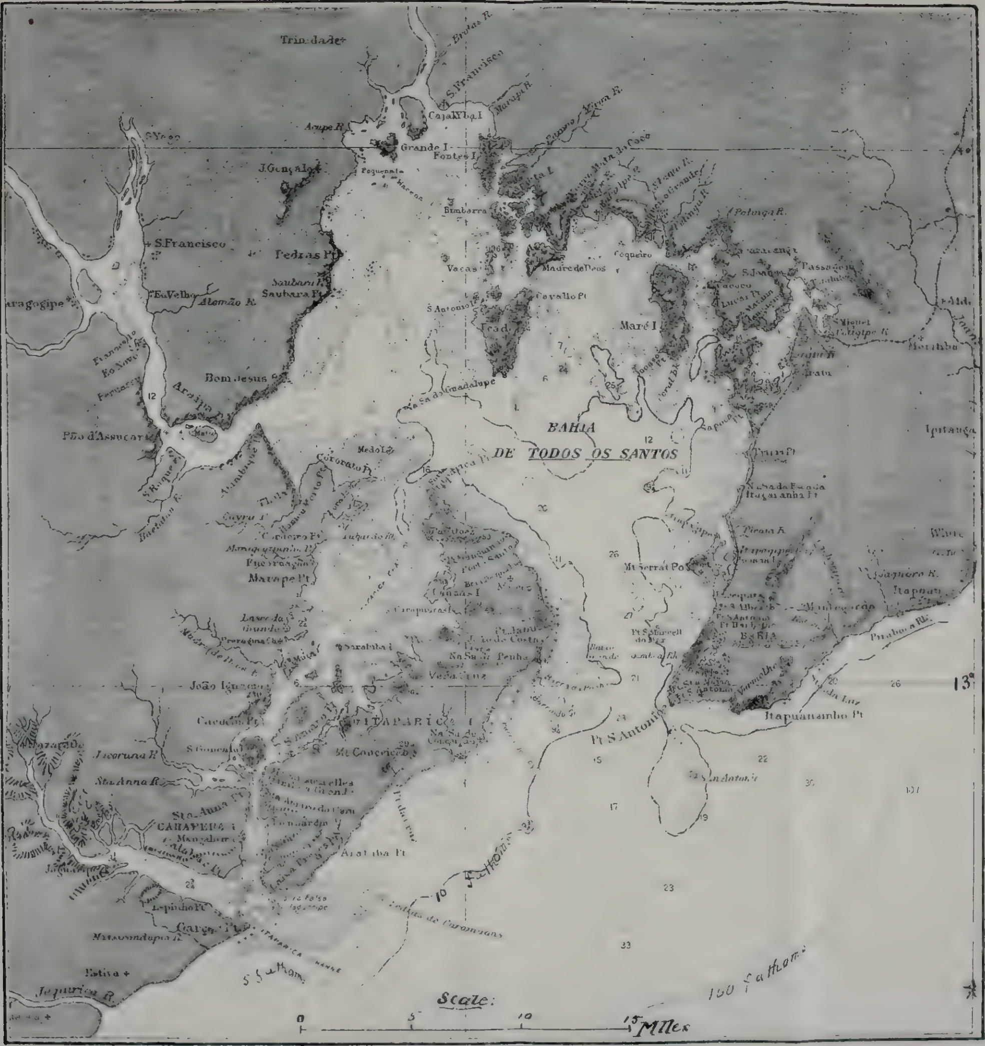
Part of chart 484

tical Miles
Flat Coral Reef
Sand
Itassepanema Reef
Channel
das Reef North
das Reef South
Mangroves
Mangrove Swamp
Stone reef
SANTA-CRUZ


SANTA CRUZ BAY
Surveyed by Capt. E. Mouchez, Fr. N. 1863.
Santa Cruz Church { Lat. 16° 17' 20" S / Long. 39° 2' 08" W. of Gr.
H.W.F.&C. 3h 40m, Springs rise 6 feet
SOUNDINGS IN FEET
Part of chart 484
Scale of Nautical Miles
Cables
1 Mile
Low flat land
Santo Antonio
Mangroves
Stone reef, broken in tide
BAY OF SANTA CRUZ
Large Channel
Small Channel
Itassepanema Reef
Flat coral
sand
Alagadas Reef North
Alagadas Reef South
Anchorage with N.E. winds
Stone reef
Mangrove swamp
Mangroves
SANTA CRUZ
Var. 7° W.


S.Yago
S.Francisco
Passagem
aragogipe
Eo.Velho
Alemão
S.Miguel
Cotegipe R.
Bom
Araipe R.
12
Pão d'Assucar
4
S.Roque
Ipitanga
Itapoan
Pitaboa Pt.
João
20
26
13°
Nazareth
Jacaruna R.
Sta.Anna R.
Estiva
Jequirica R.

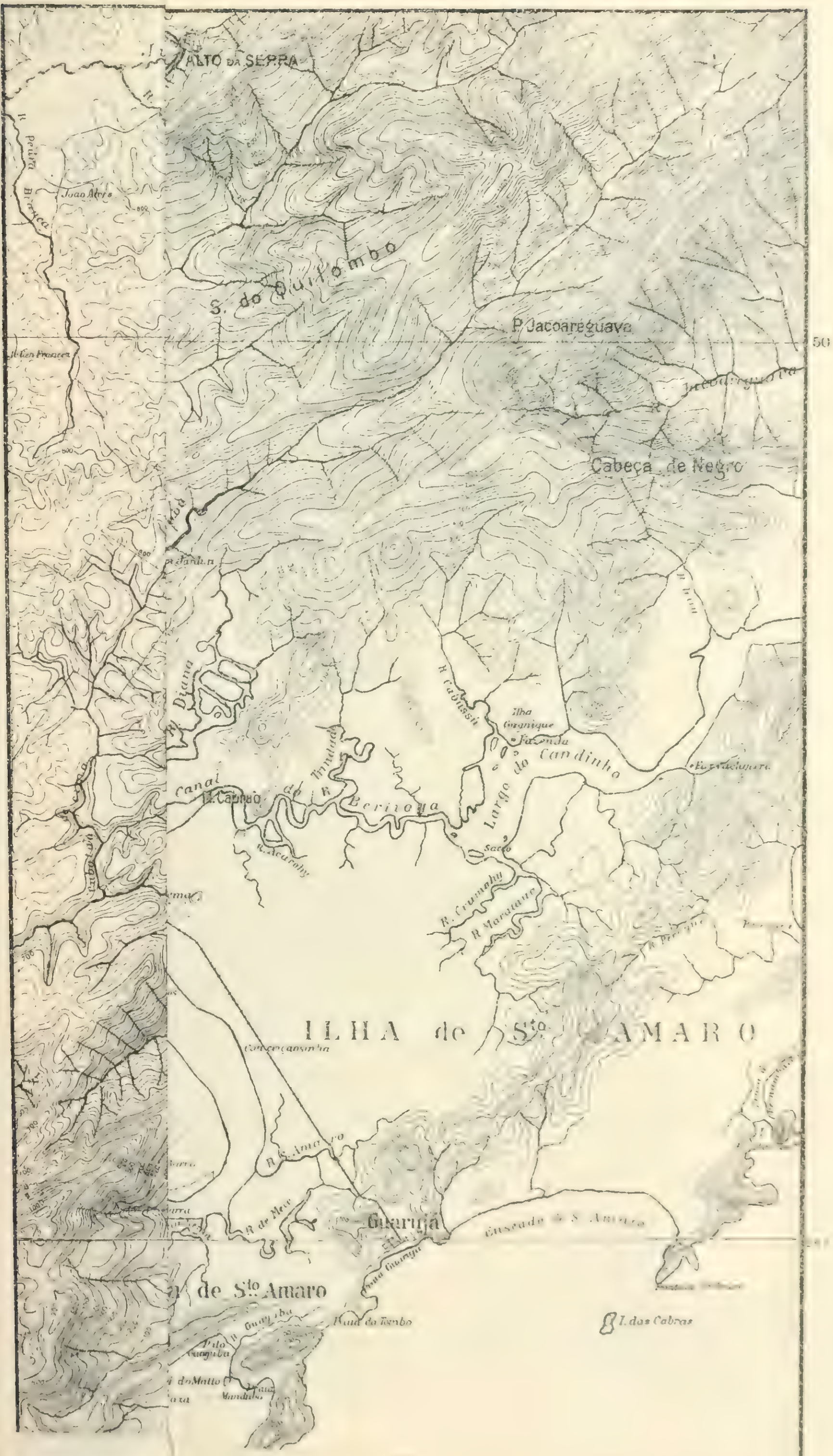
MAP OF THE FINDINGS

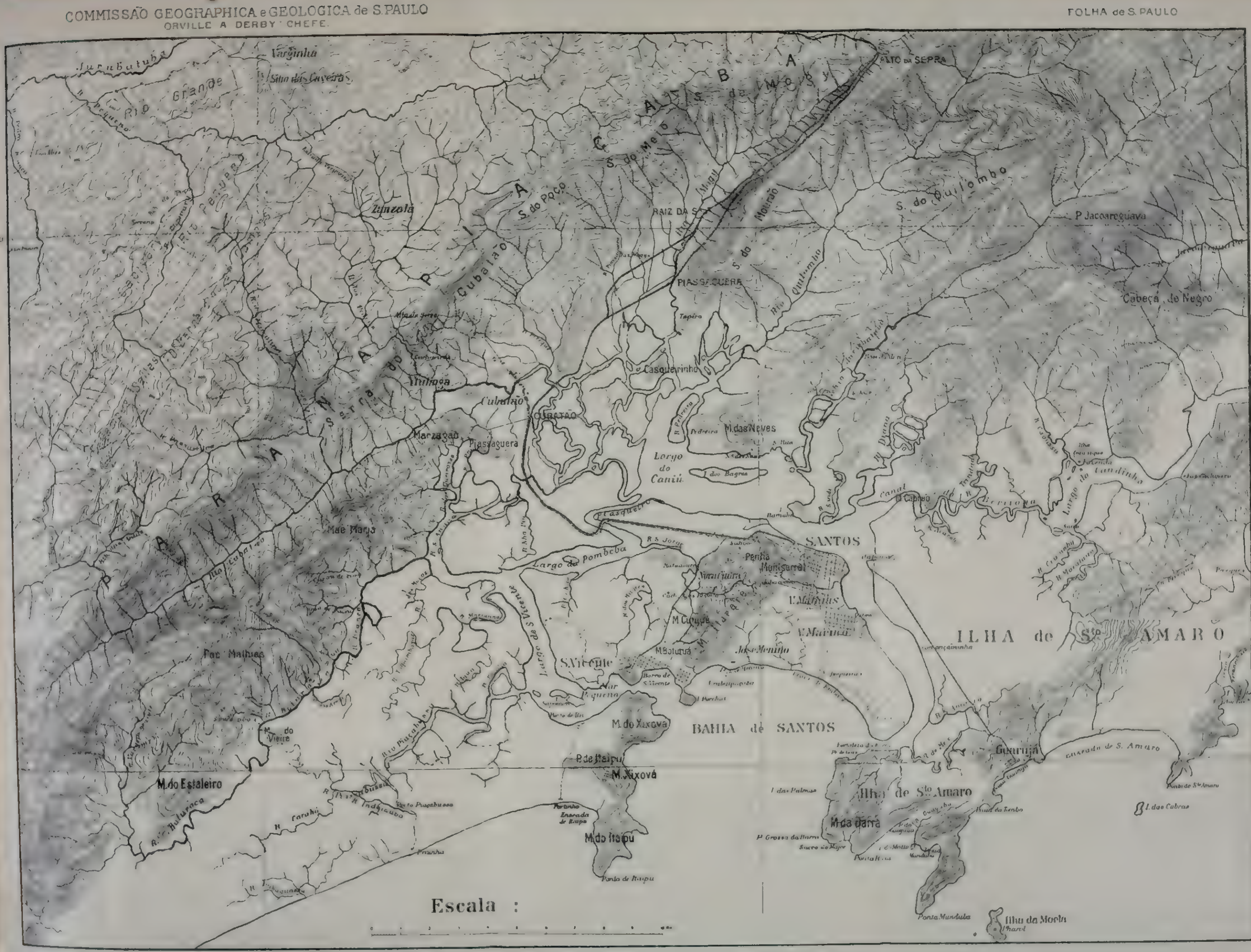

Trindade
S. Francisco
Cajaiba I
Grande I
Fontes I
J. Gonçalo
Bimbarra
S. Francisco
Pedras Pt
Vacas
Madre de Deos
Saubara Pt
Cavallo Pt
Maré I
Frad
Bom Jesus
Na Sa da Guadalupe
Pão d'Assucar
BAHIA
DE TODOS OS SANTOS
Medo I
Itaparica
Mt Serrat Pt
Marape Pt
Itapoan
Itaparica
Vera Cruz
Cacaba Pt
Mt Conceição
João Ignacio
Carapeba
Itapuansinho Pt
Pt S Antonio
Ipitanga
13°
10 fathoms
5 fathoms
100 fathoms
Scale:
0
5
10
15 Miles

Map of the Bay of Bahia; a part of Hydrographic Chart No. 1522. Most of the soundings given on the original are here omitted.

(Many of the names are incorrectly spelled)

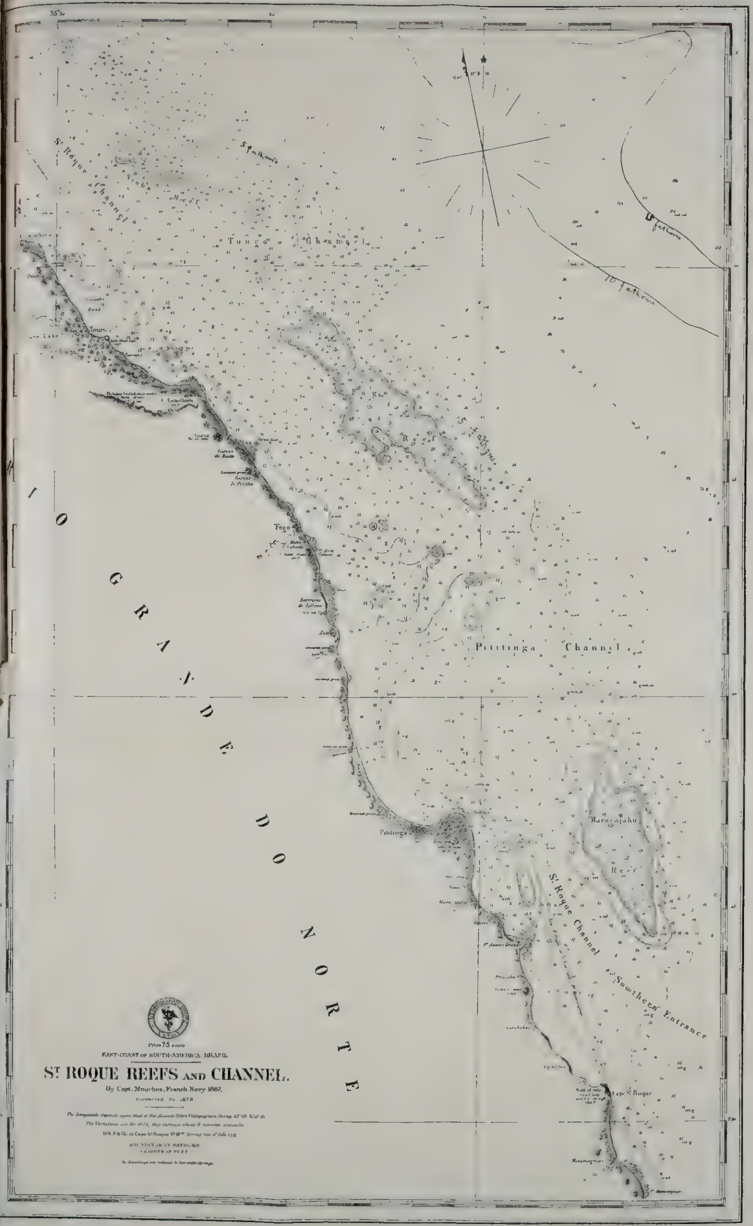
FOLHA de S. PAULO


ALTO DA SERRA
R. Pedra Branca
Joao Alves
S. do Quilombo
P. Jacoareguava
50
Jacoareguava
Cabeça de Negro
R. Diana
Canal de Berioga
I. Caspao
R. Trindade
R. Acarahy
R. Cabussu
Ilha Guanique
Fazenda
Largo do Candinho
Sacco
R. Crumahy
R. Maratauè
R. Pereque
ILHA de S.to AMARO
Conceiçãosinha
R. S. Amaro
R. de Meio
Guarujá
Enseada de S. Amaro
de S.to Amaro
R. Guarujiba
Ponta do Tombo
I. das Cabras
doMatto
Mandubi

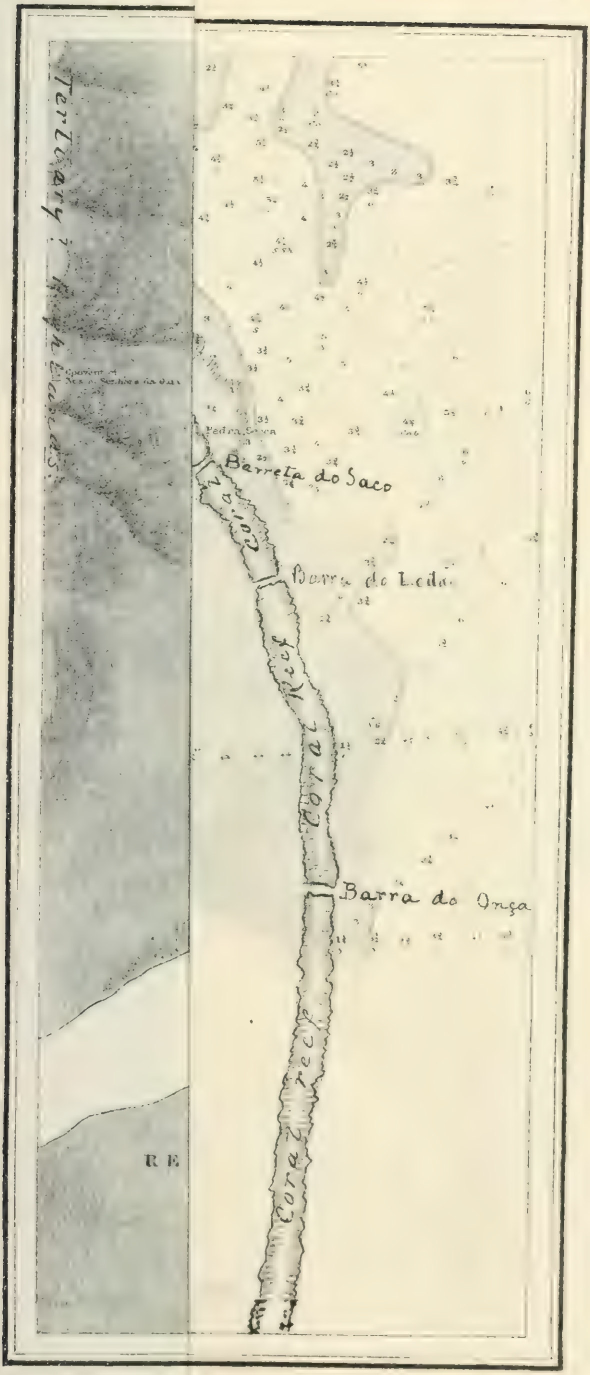

COMMISSÃO GEOGRAPHICA e GEOLOGICA de S.PAULO
ORVILLE A DERBY CHEFE.
FOLHA de S.PAULO
Jurubatuba
Varginha
Sitio das Caveiras
Rio Grande
R. Pequeno
Rio Pequeno
S. do Mello
S. do Poço
S. do Quilombo
ALTO da SERRA
RAIZ DA S.
P Jacoareguava
Zanzolá
Cubatão
PIASSAGUERA
R. Quilombo
Cabeça de Negro
Casqueirinho
Mulunga
Cubatão
CUBATÃO
Marzagão
Piassaguera
M. das Neves
Largo do Caniú
I. dos Bagres
Canal de Bertioga
Largo do Candinho
C. N. M. C. A. P. I. A. C. A. B. A. de Mogy
S. P. A. R. A. N. A. P. I. A. C. A. B. A.
Serra do Cubatão
Mãe Maria
Largo do Pombeba
Piassaguera
SANTOS
Penha
Monserrat
V. Mathias
V. Macuco
M. Cuçubé
M. Boturuá
M. Itararé
José Menino
S. Vicente
Mar Pequeno
Largo de S. Vicente
ILHA de Sto AMARO
Pae Mathias
M. do Vieira
M. do Xixová
BAHIA de SANTOS
P. de Itaipú
M. Xixová
Guarujá
Enseada de S. Amaro
M. do Estaleiro
R. Boturoca
R. Caruhá
Rio Piaçabuçu
Enseada de Itaipú
M. do Itaipú
Ponta de Itaipú
Ilha de Sto Amaro
M. da Barra
I. das Palmas
I. das Cabras
Ponta de Sto Amaro
Ponta Munduba
Ilha da Moela
Pharol
Escala :

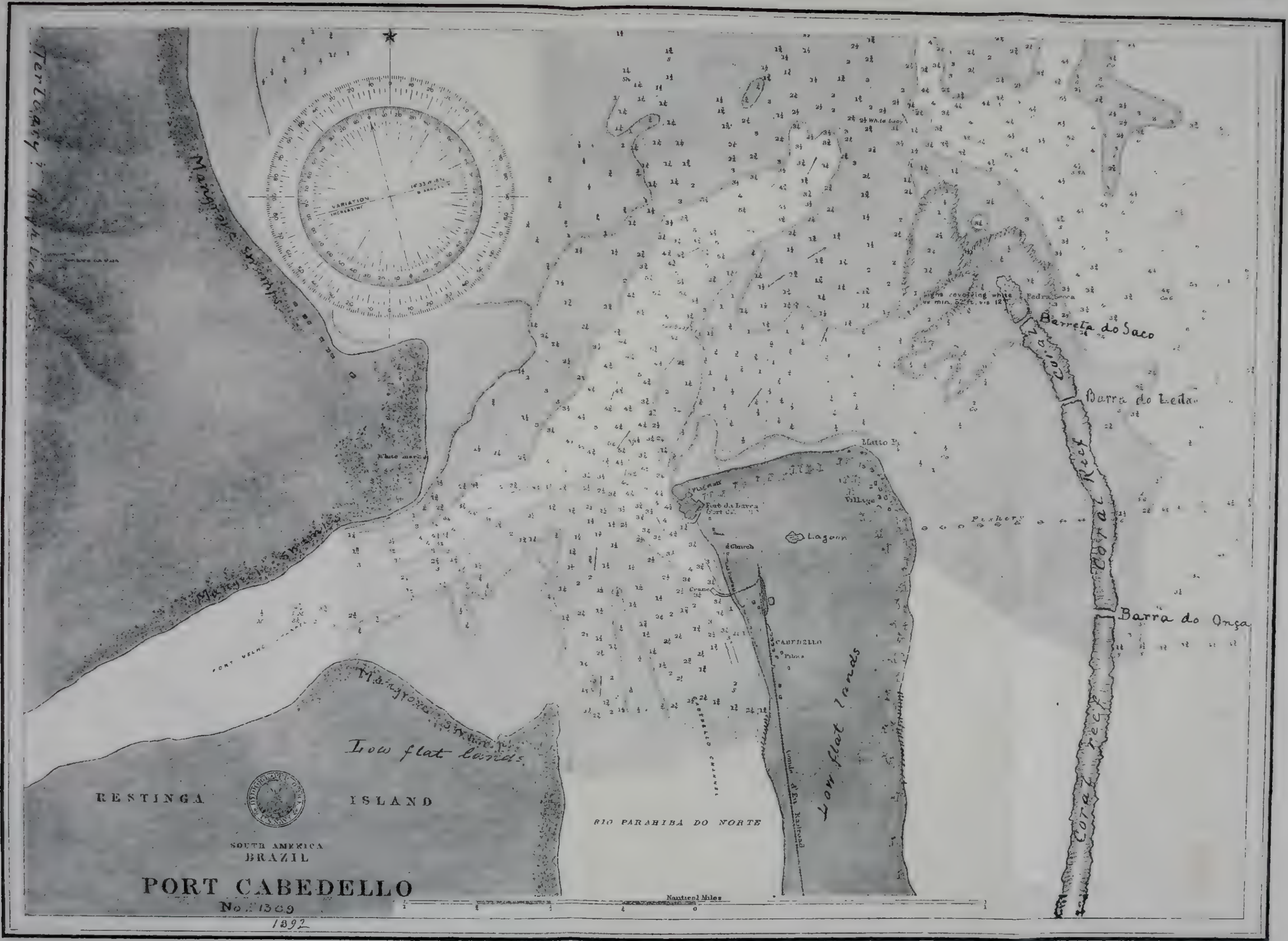
Topographic Map of the Brazilian coast about Santos, showing how the coastal mountains have been submerged, leaving their peaks as islands or as hills in a flat swampy region. (Reduced from the São Paulo sheet of the Commissao Geologica de S. Paulo.)

35°30'

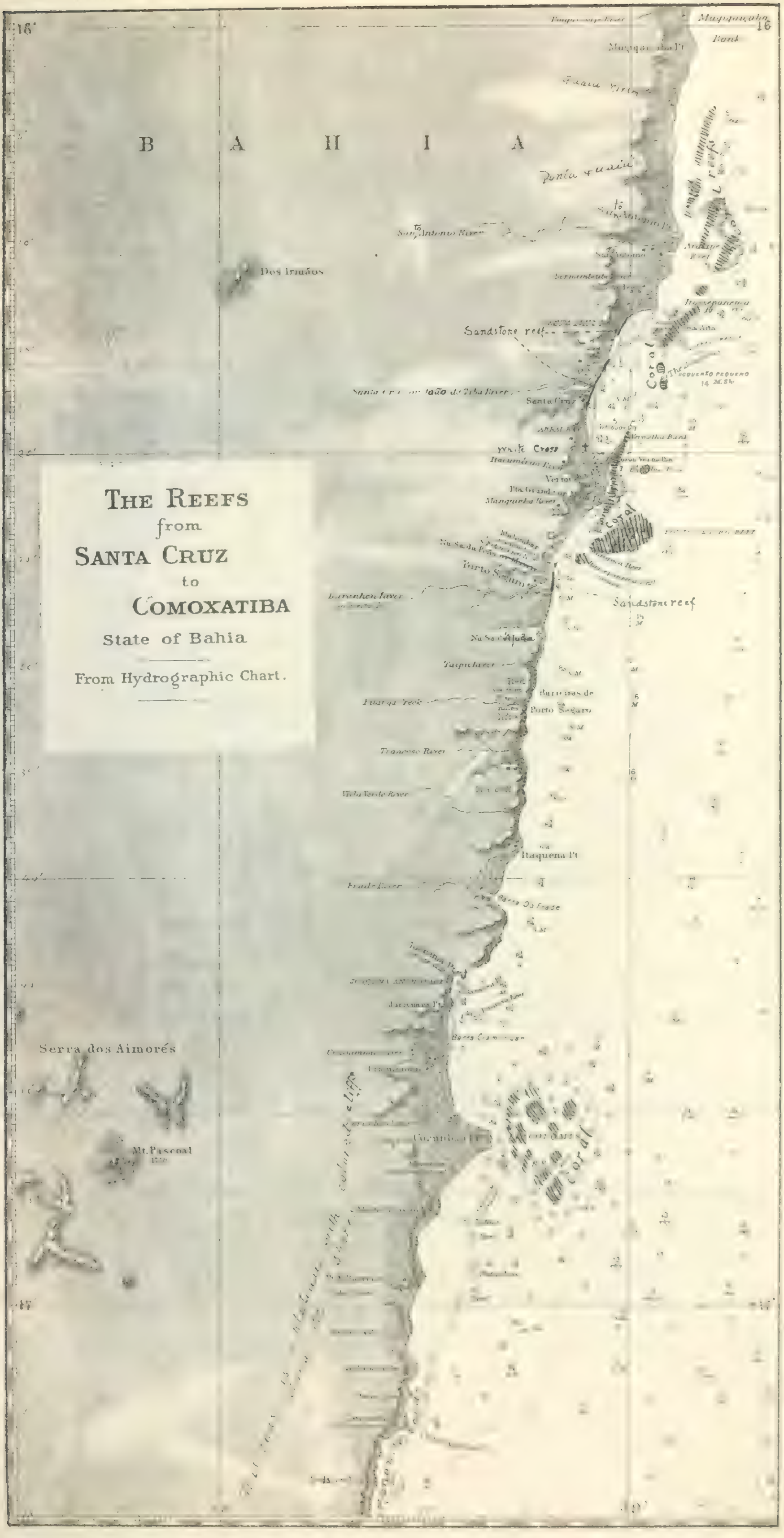

S^t Roque Channel
Reef
5 fathoms
Touro Channel
Touro
C. Camalhero
Fogo Reef
5 fathoms
Fogo
Pititinga Channel
Pititinga
Maracajahu Reef
S^t Roque Channel
Southern Entrance
Cape S^t Roque
5 fathoms
10 fathoms
RIO GRANDE DO NORTE
Price 75 cents
EAST-COAST OF SOUTH-AMERICA BRAZIL
S^T ROQUE REEFS AND CHANNEL.
By Capt. Mouchez, French Navy 1867,
corrected to 1878
SOUNDINGS IN FATHOMS
HEIGHTS IN FEET

Part of Hydrographic Chart No. 481. Showing the reefs about Cape St. Roque.


Tertiary highlands
Pedra Secca
Barreta do Saco
Coral
Barra do Leda
Coral Reef
Barra do Onça
Coral reef
R E


Tertiary? High lands
Mangrove Swamps
Mangrove Swamps
Mangrove Swamps
White mark
VARIATION INCREASING
White buoy
Pedra Secca
Barreta do Saco
Coral Reef
Barra do Leitão
Matto Pt
Fort da Barra
Village
Lagoon
Church
Crane
CABEDELLO
Fishery
Coral Reef
Barra do Onça
Coral reef
Low flat lands
Low flat lands
RESTINGA ISLAND
SOUTH AMERICA
BRAZIL
PORT CABEDELLO
No. 1309
1892
RIO PARAHIBA DO NORTE
CABEDELLO CHANNEL
Nautical Miles

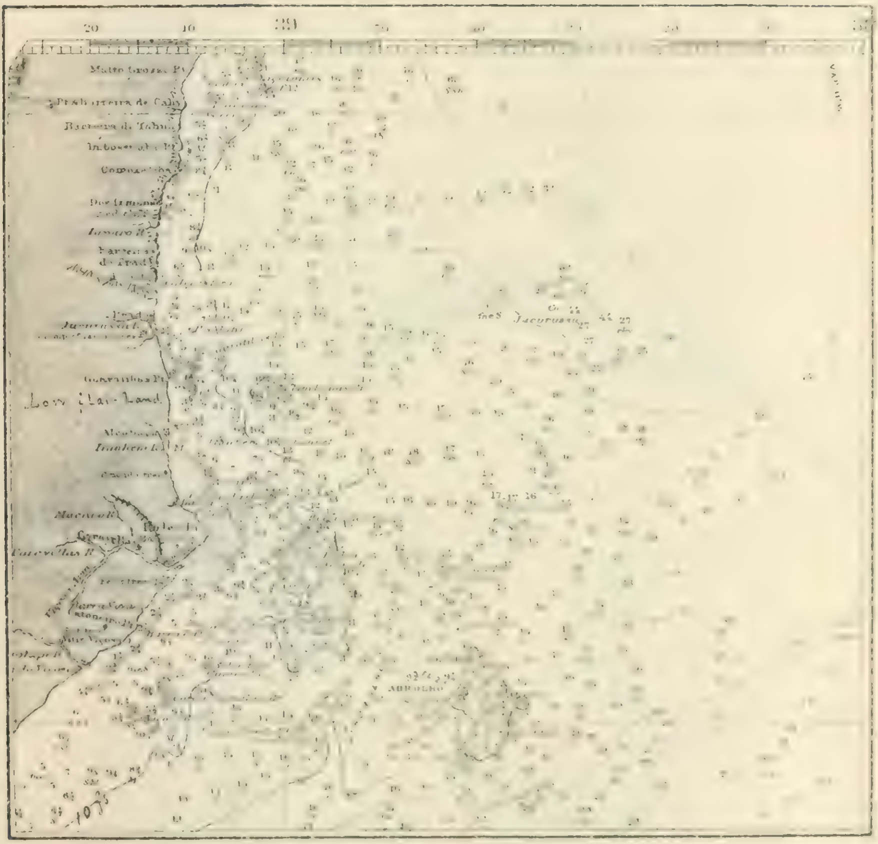
Part of Hydrographic Chart of the mouth of Rio Parahiba Do Norte, to show the coral reef and its relation to the adjoining coast.



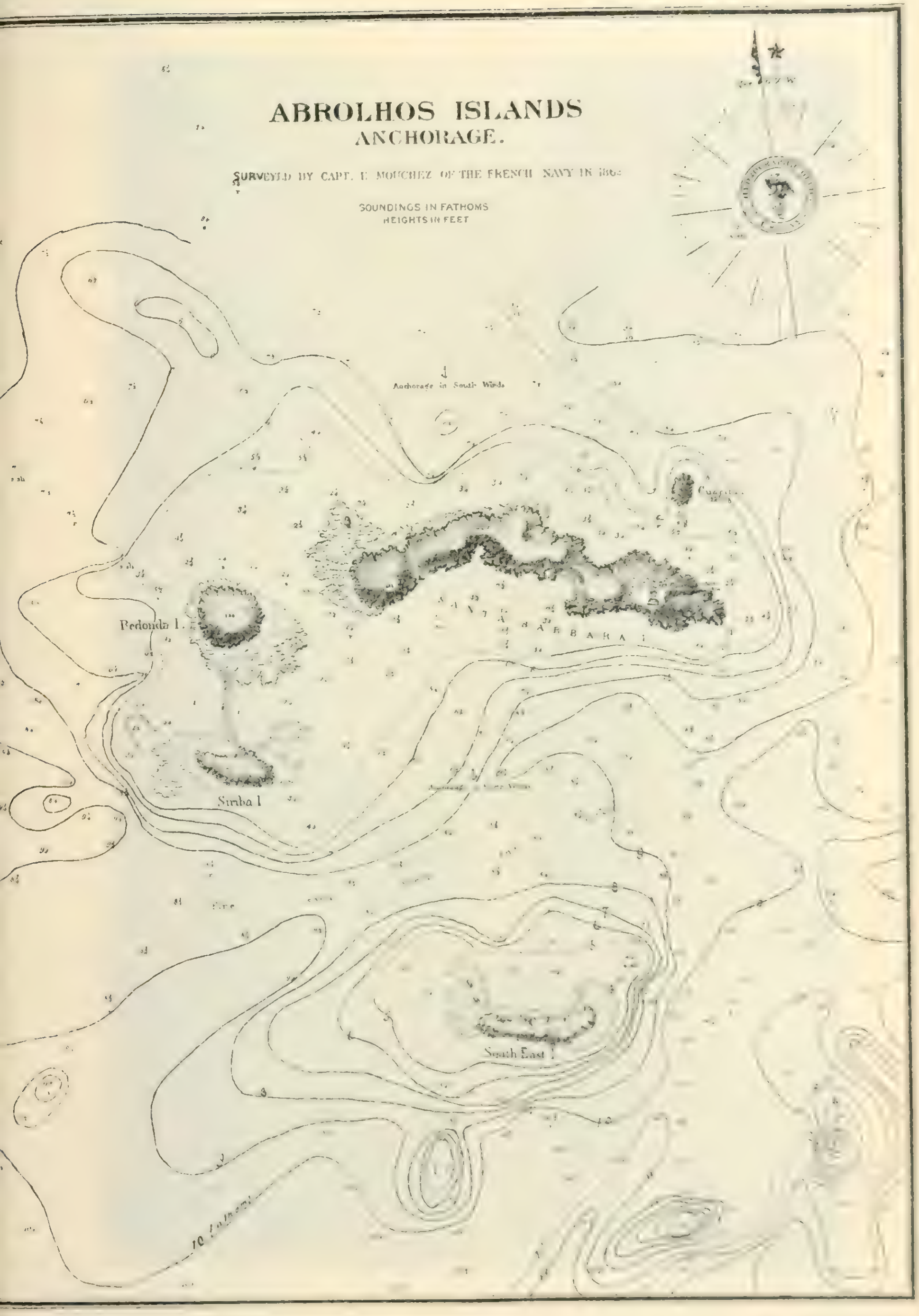
THE REEFS
from
SANTA CRUZ
to
COMOXATIBA
State of Bahia

From Hydrographic Chart.

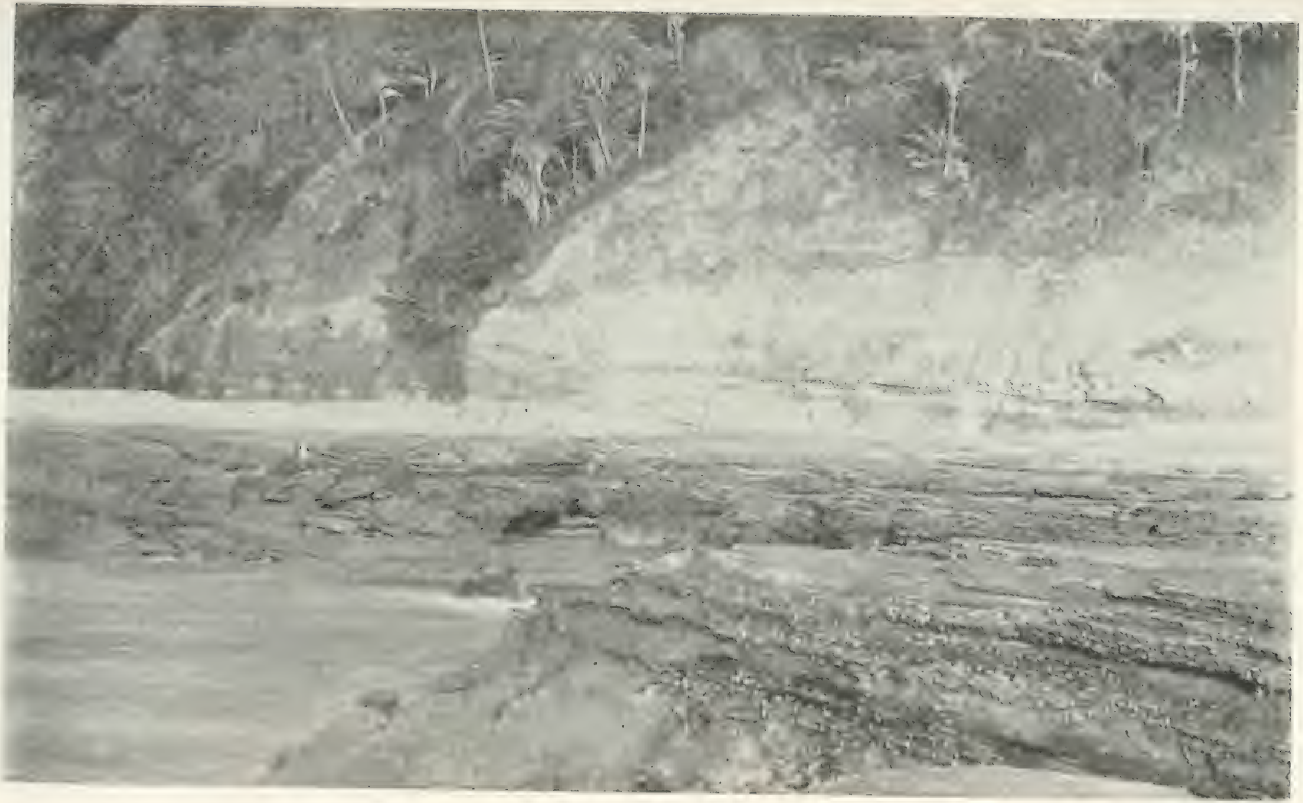
BAHIA
16
Maquiçabo Pt
Ponta d'aiu
S. Antonio River
Dos Irmãos
Araripe Reef
Itassepanema
Coral
Sandstone reef
Santa Cruz or João de Tiba River
Santa Cruz
Vermelha Bank
White Cross
Coral
Porto Seguro
Sandstone reef
Buranhem River
Na Sa d'Ajuda
Barreiras de Porto Segaro
Trancoso River
Itaquena Pt
Frade River
Barra do Frade
Serra dos Aimorés
Mt Pascoal
Corumbau Pt
Coral


20
10
Matto Grosso Pt
Low Flat Land
Abrolhos

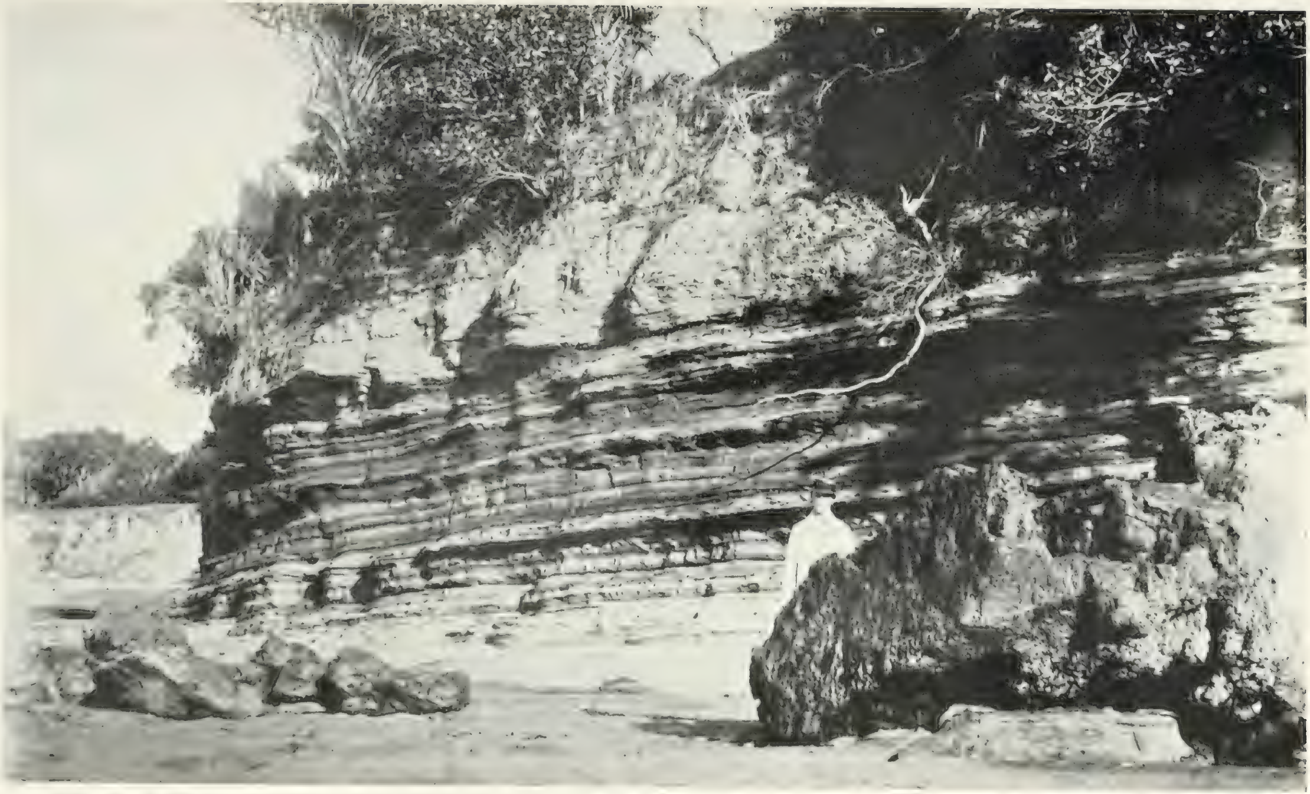
PART OF THE HYDROGRAPHIC CHART SHOWING THE LIXA, PARCEL DAS PAREDES AND ABROLHOS CORAL REEFS.


ABROLHOS ISLANDS
ANCHORAGE.
SURVEYED BY CAPT. E. MOUCHEZ OF THE FRENCH NAVY IN 186[illegible]
SOUNDINGS IN FATHOMS
HEIGHTS IN FEET
Anchorage in South Winds
Guarita
SANTA BARBARA I
Redonda I.
Siriba I
South East I
10 fathoms

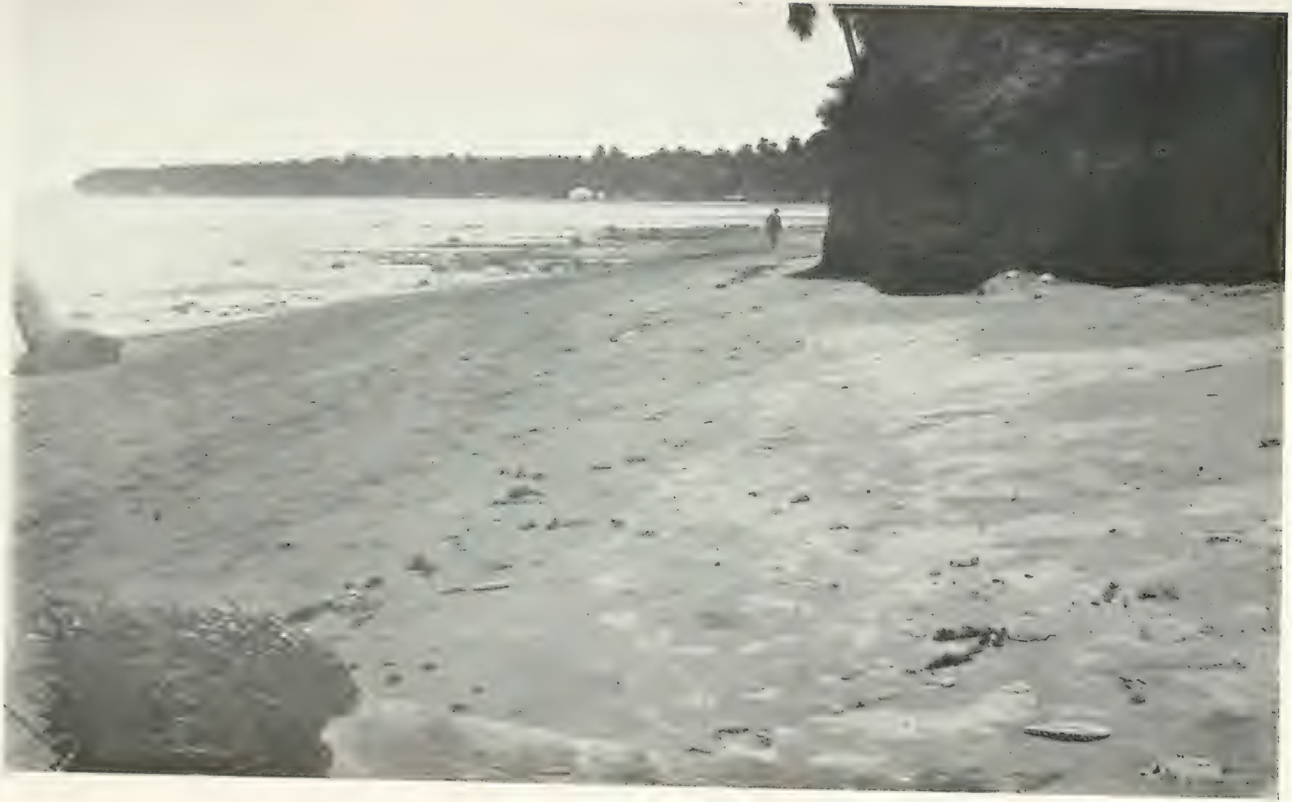
PART OF THE HYDROGRAPHIC CHART OF THE ABROLHOS ISLANDS



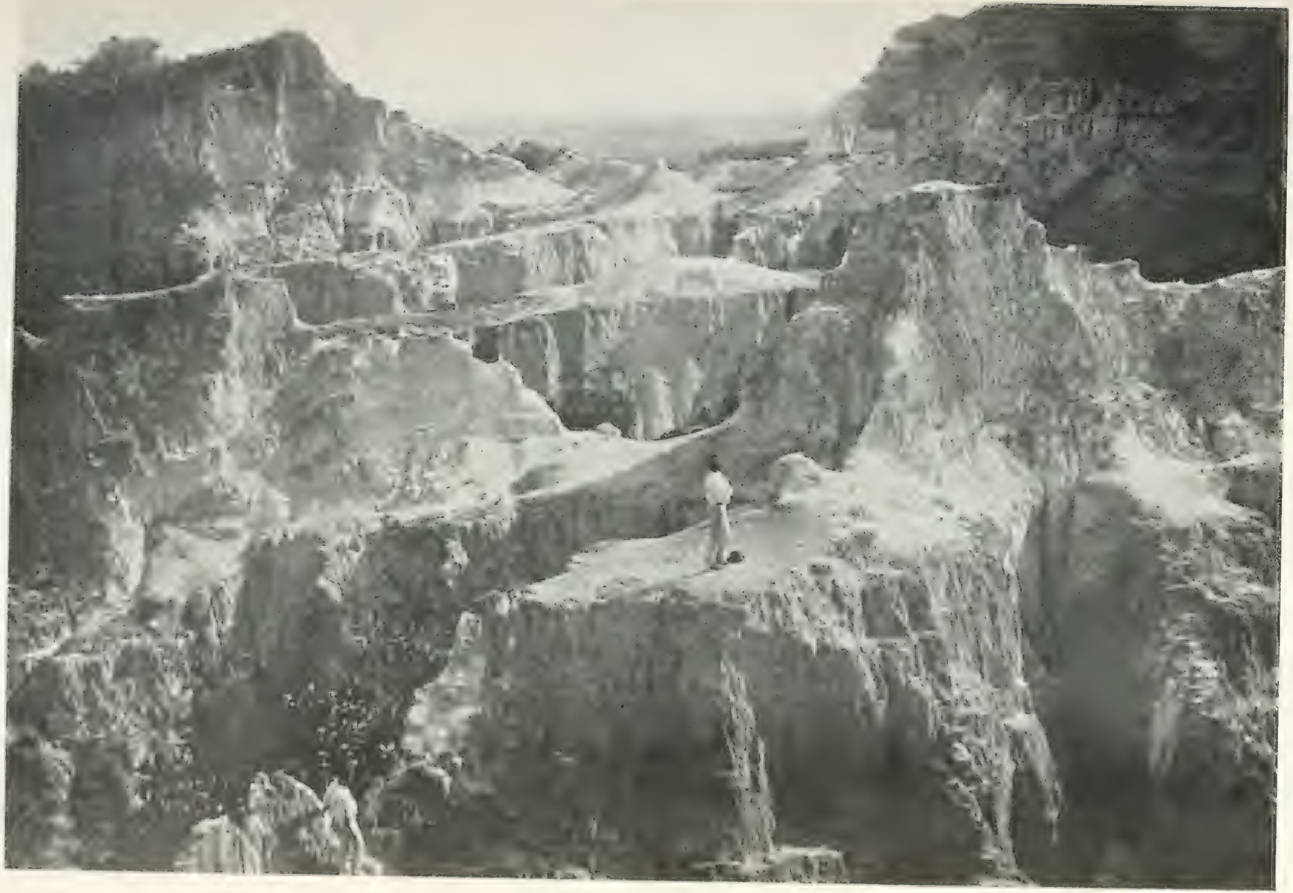
THE TERTIARY (?) CLIFFS AT BARREIRA DO CAMARAGÍBE.



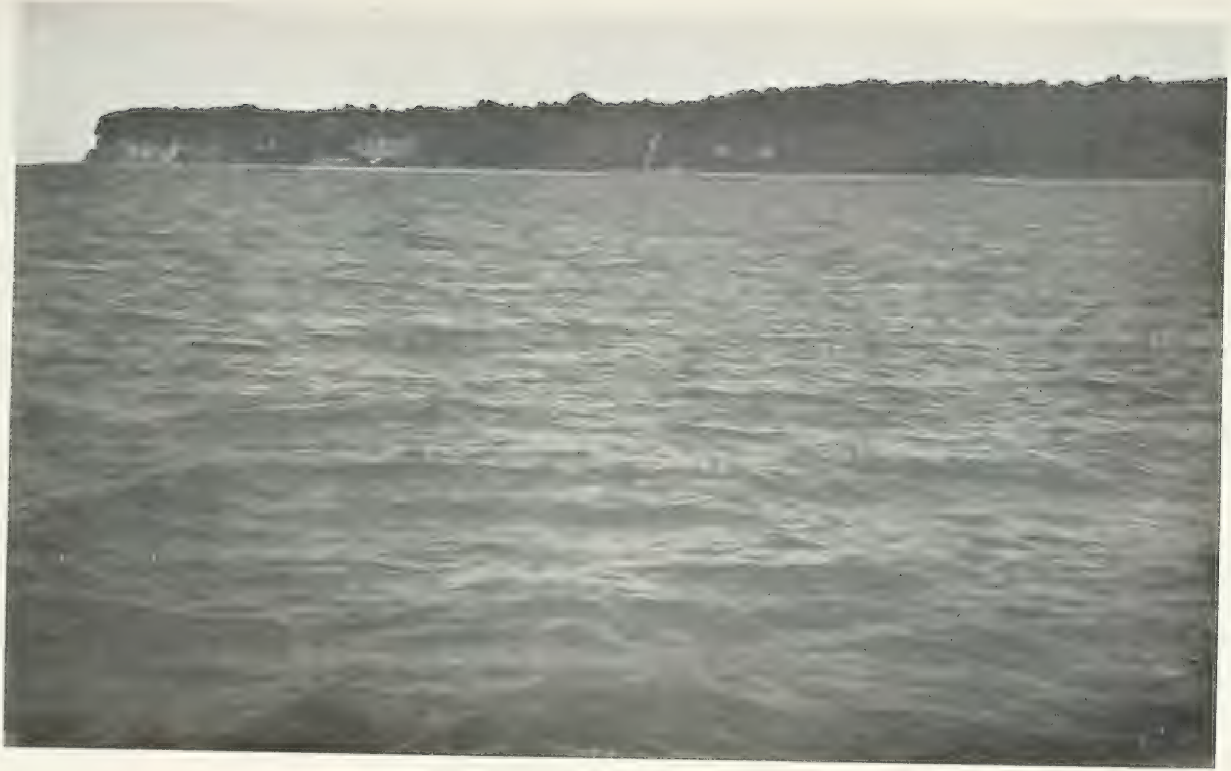
TERTIARY (?) SANDSTONES AND SHALES SOUTH OF BARREIRA DO CAMARAGIBE.



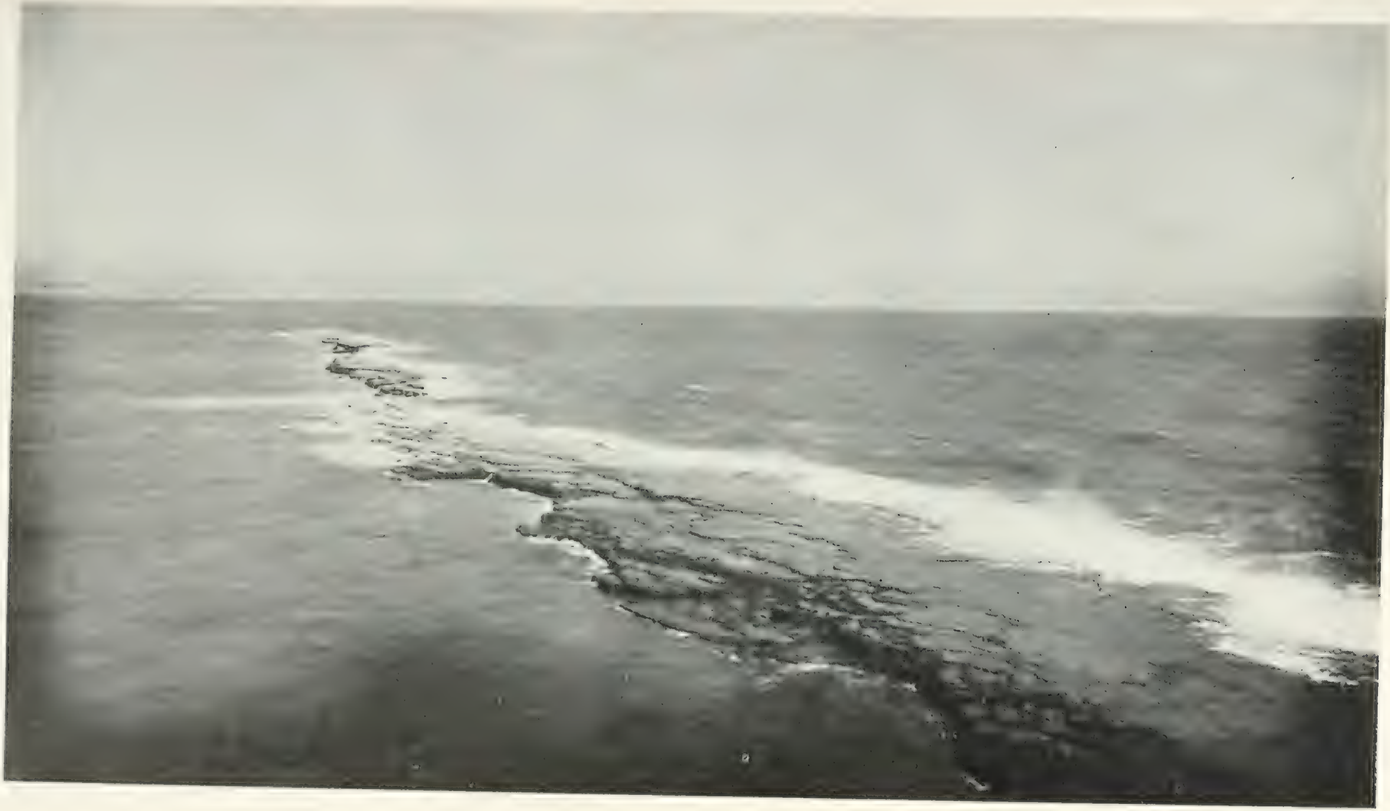
BEACH AT CAMAXO ON THE COAST OF ALAGOAS.



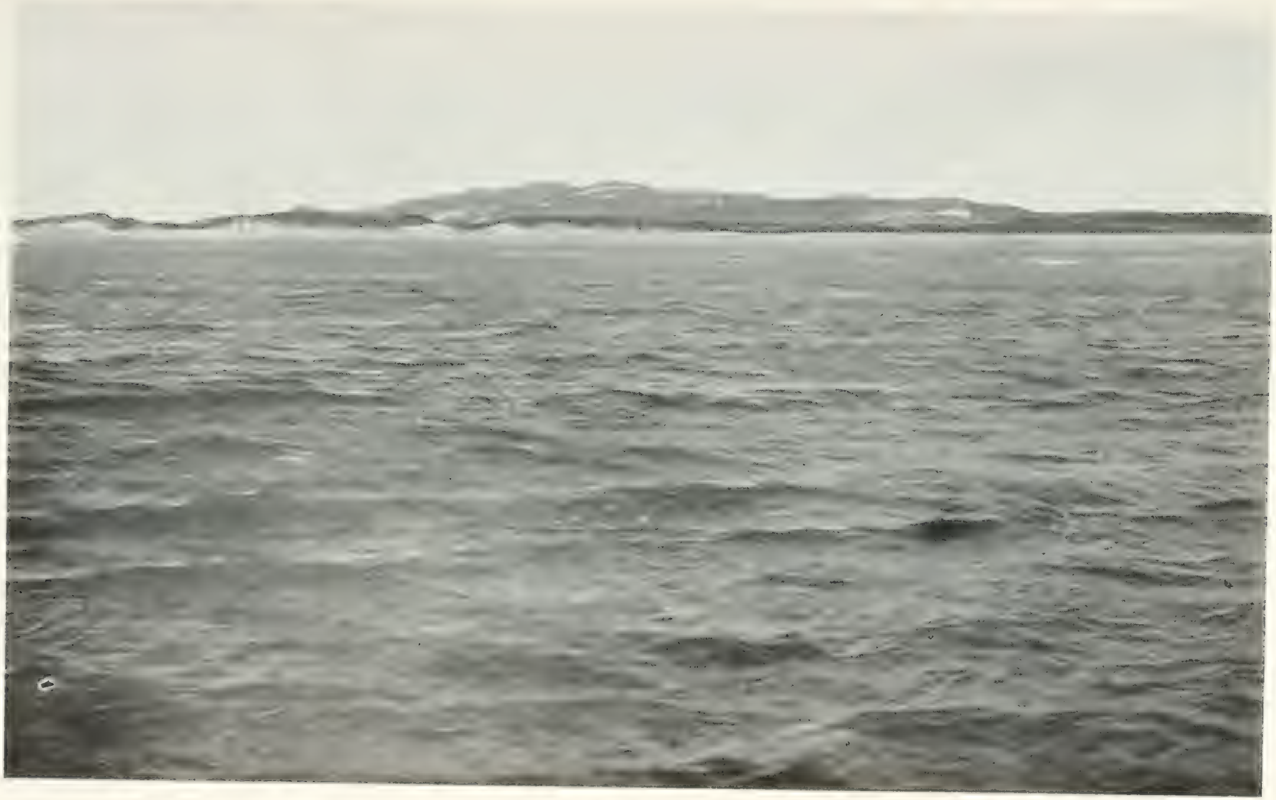
RUINAS DE PALMYRA NEAR OLINDA.



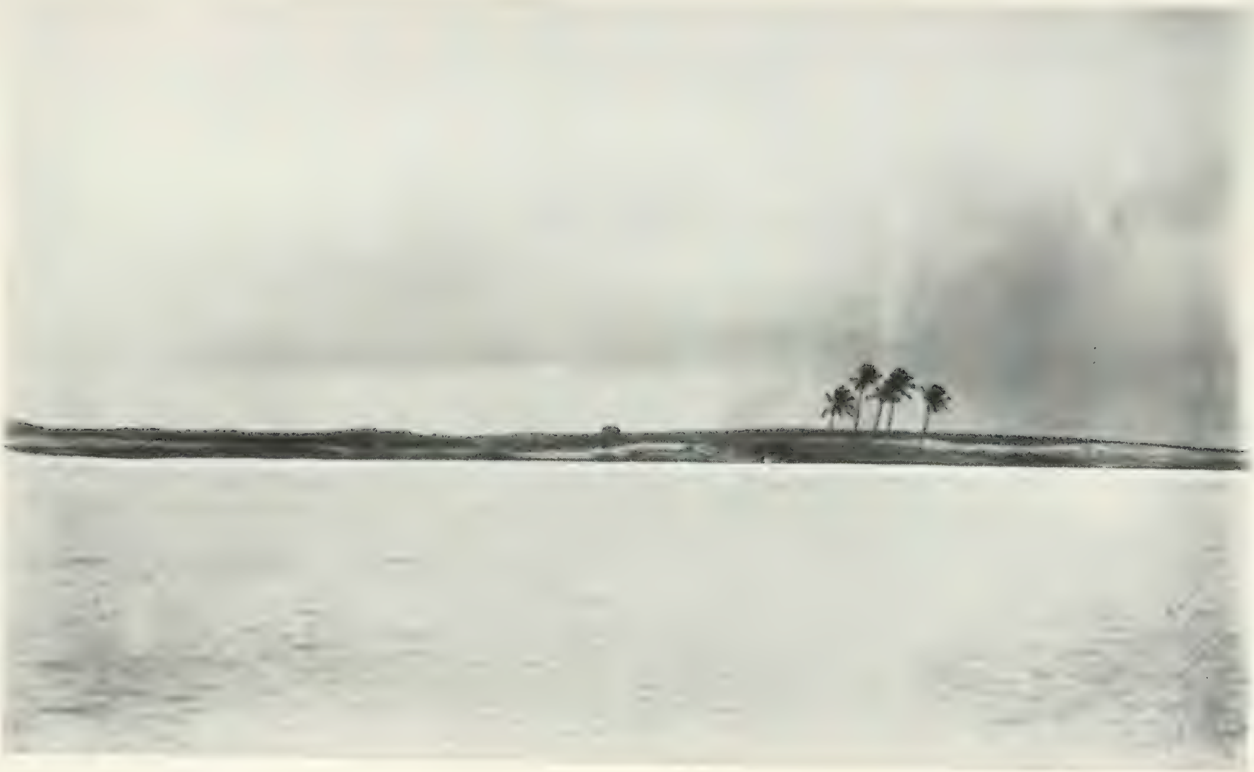
CAPE BRANCO, PARAHYBA DO NORTE.



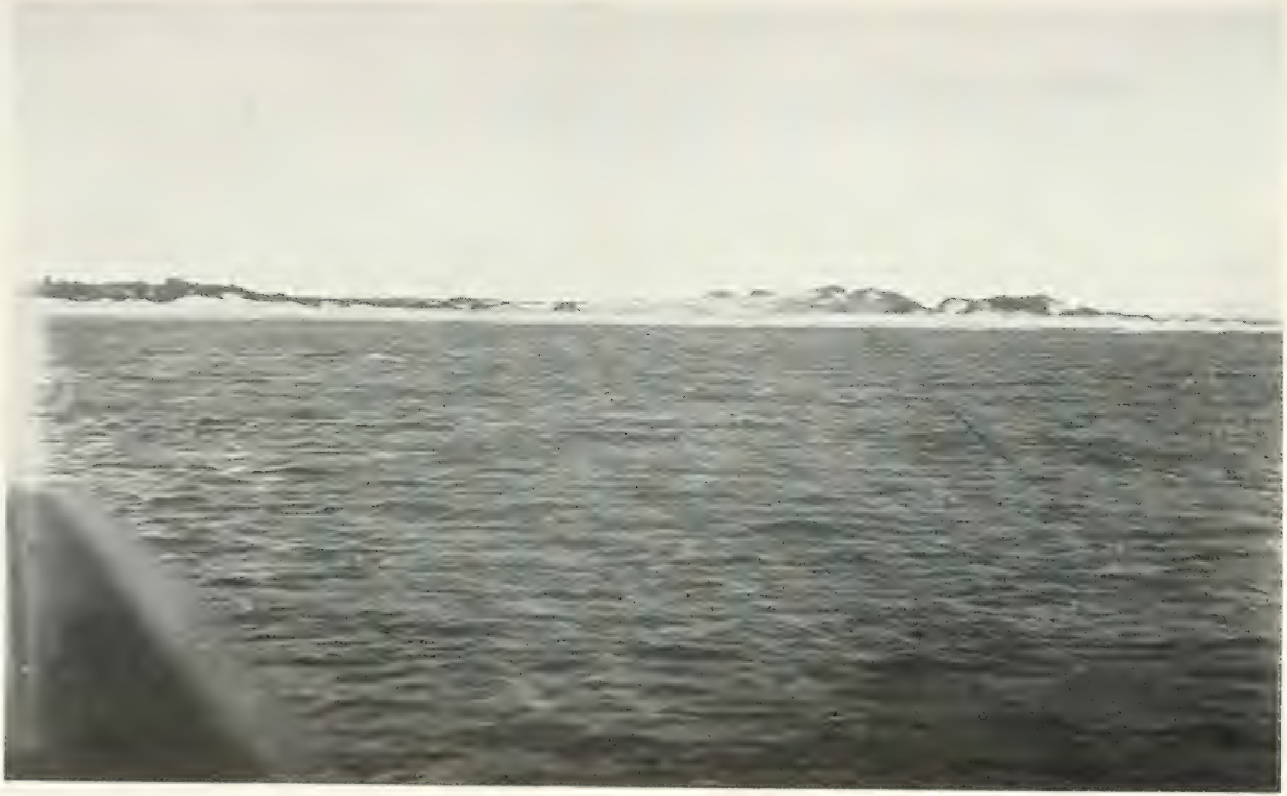
THE SANDSTONE REEF AT NATAL, RIO GRANDE DO NORTE.



THE REEF AT NATAL, RIO GRANDE DO NORTE.

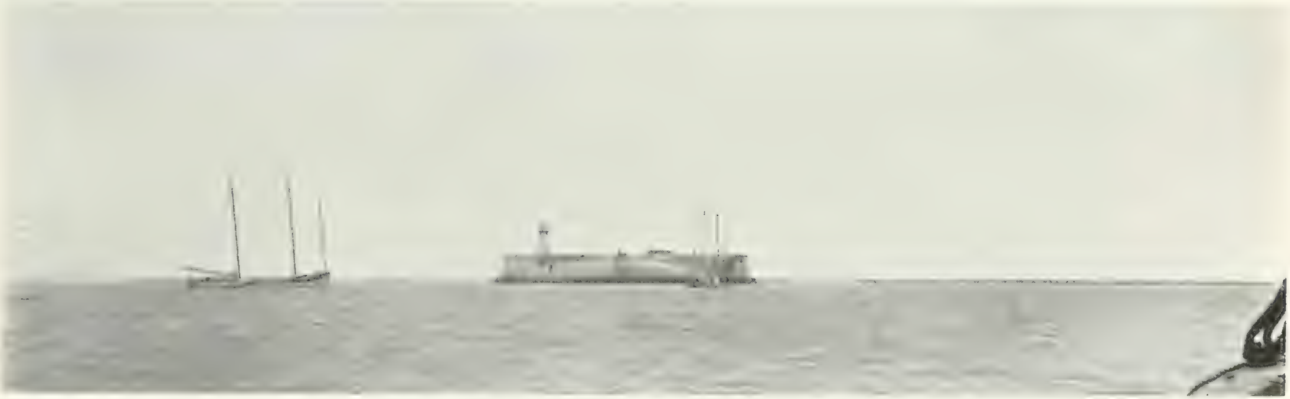


DUNES SOUTH OF RIO GRANDE DO NORTE.

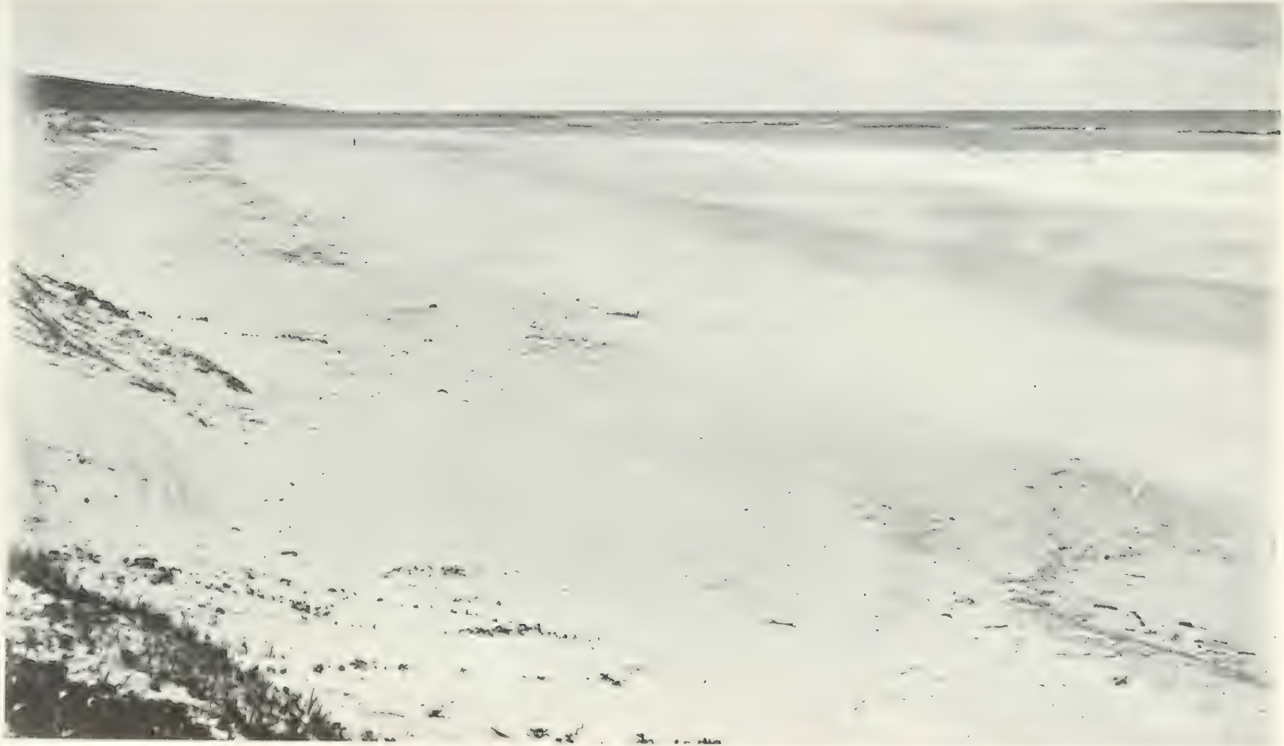


DUNES NORTH OF THE MOUTH AT RIO GRANDE DO NORTE.

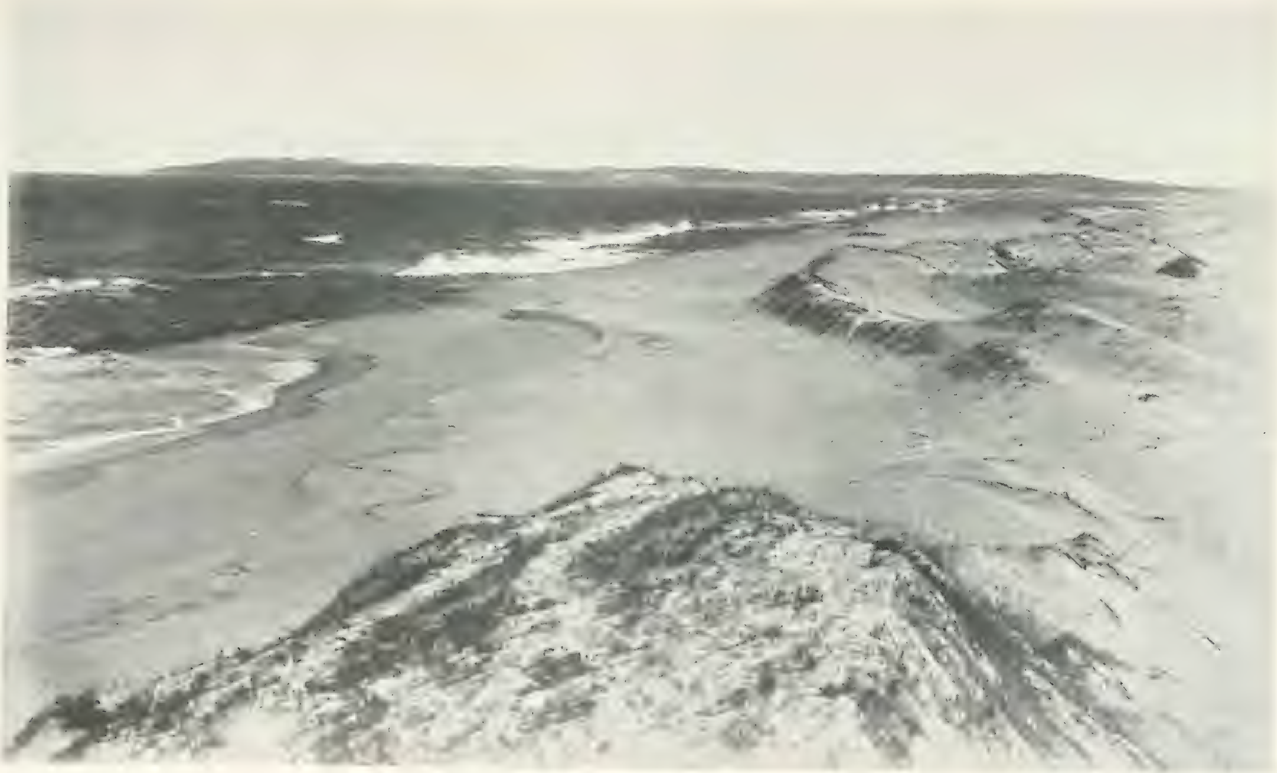
STONE REEF AT RIO GRANDE DO NORTE.



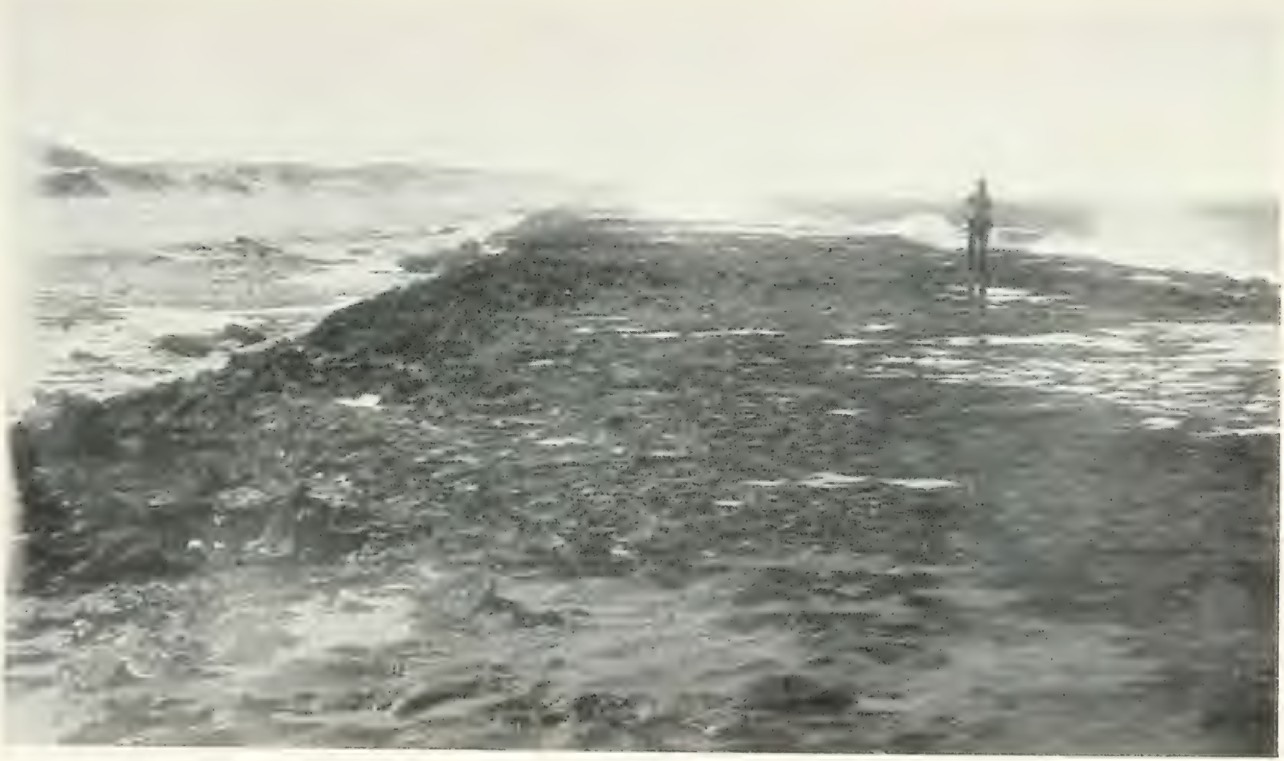
STONE REEF AT RIO GRANDE DO NORTE.



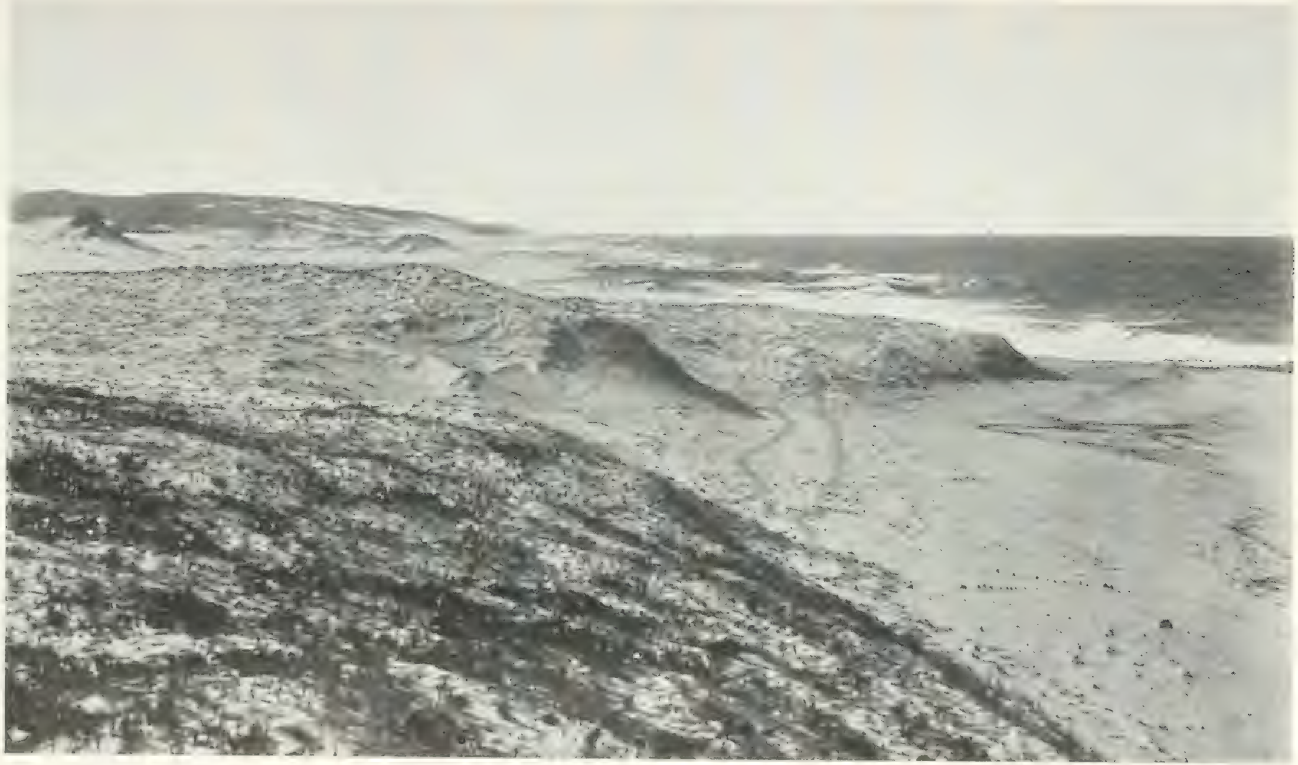
SOUTHERN PART OF CUNHAHU STONE REEF



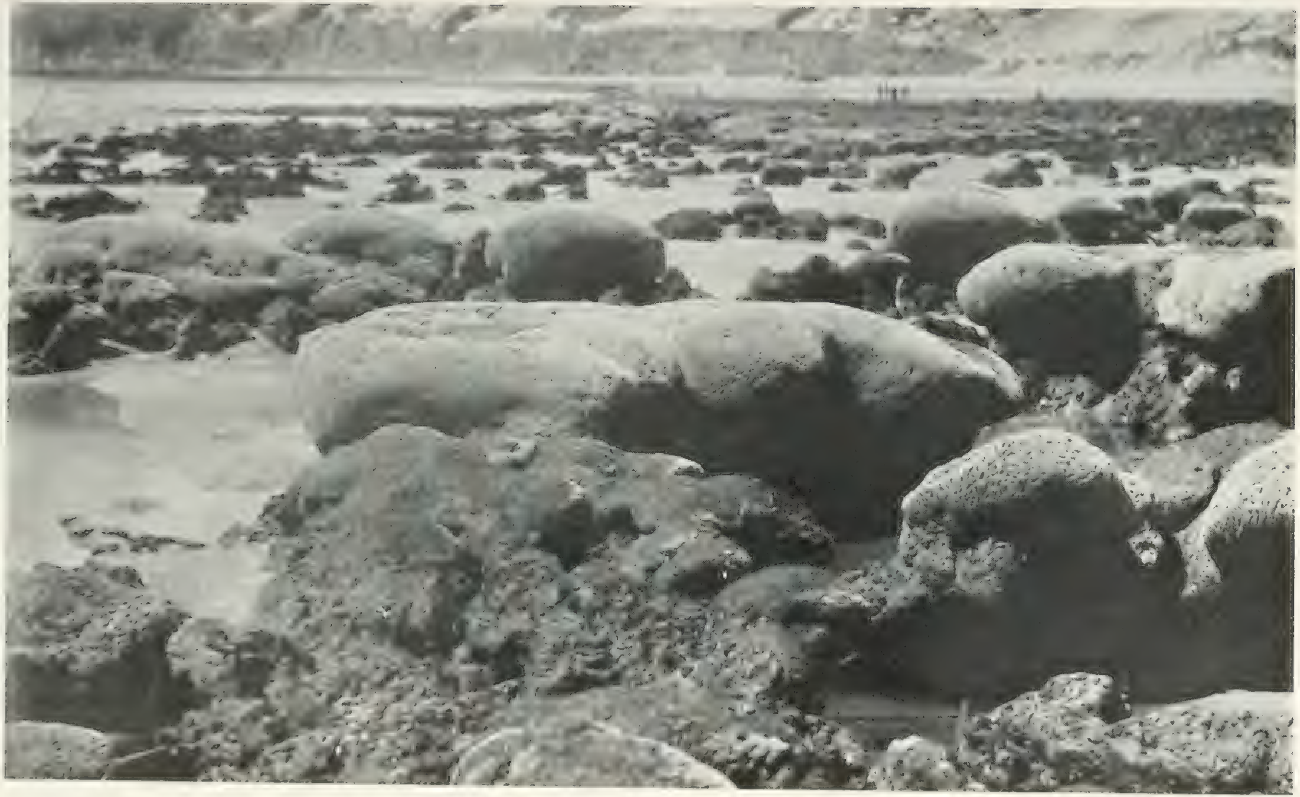
NORTH END OF THE CUNHAHU STONE REEF.



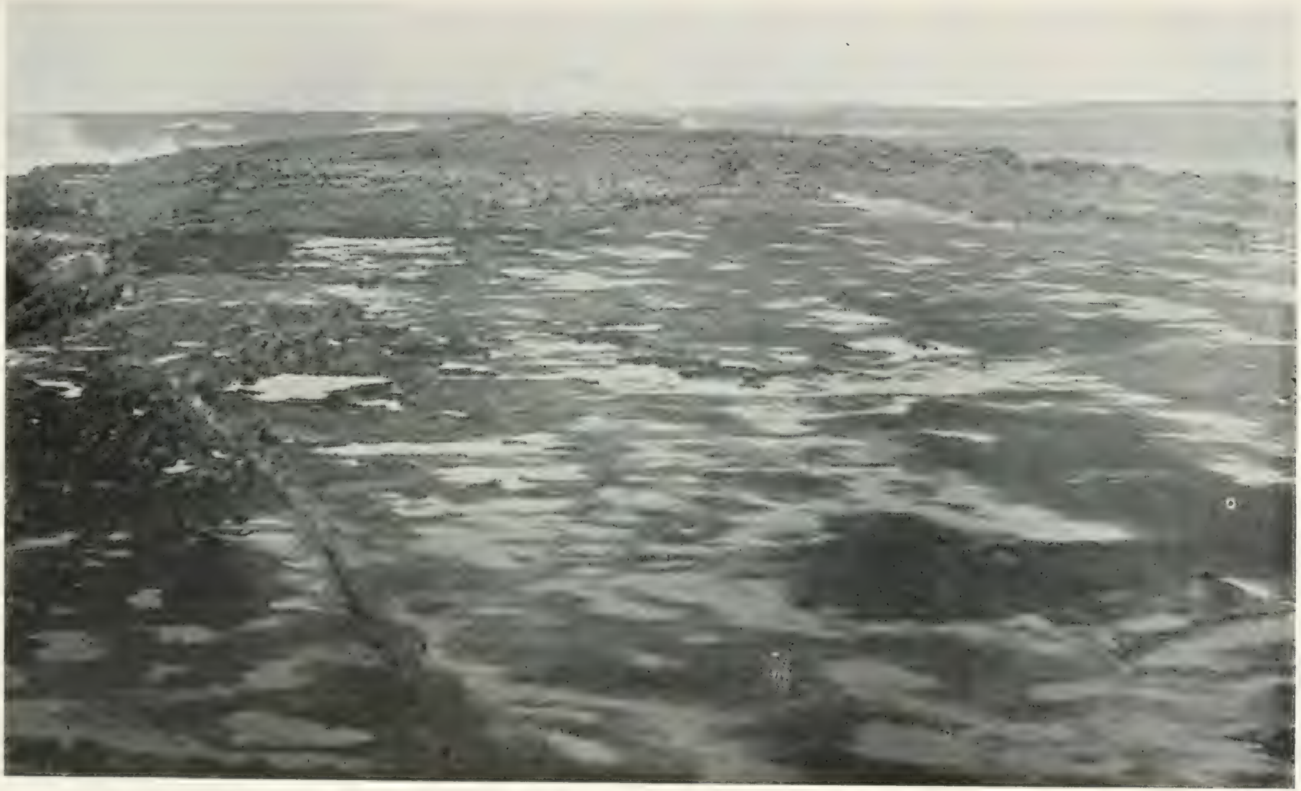
THE NORTH END OF THE CUNHAHU STONE REEF.



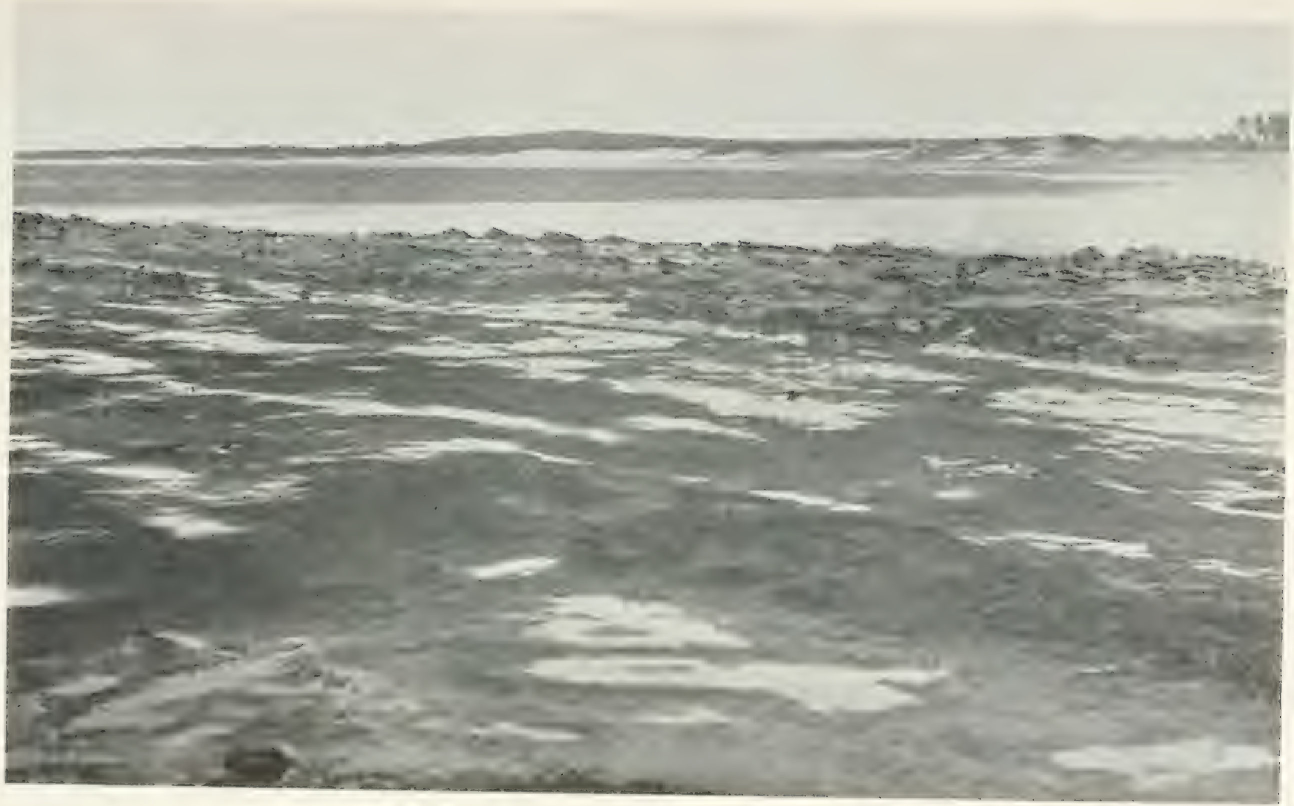
PONTA DA PIPA AND NORTH END OF THE SIBAÚMA REEF.



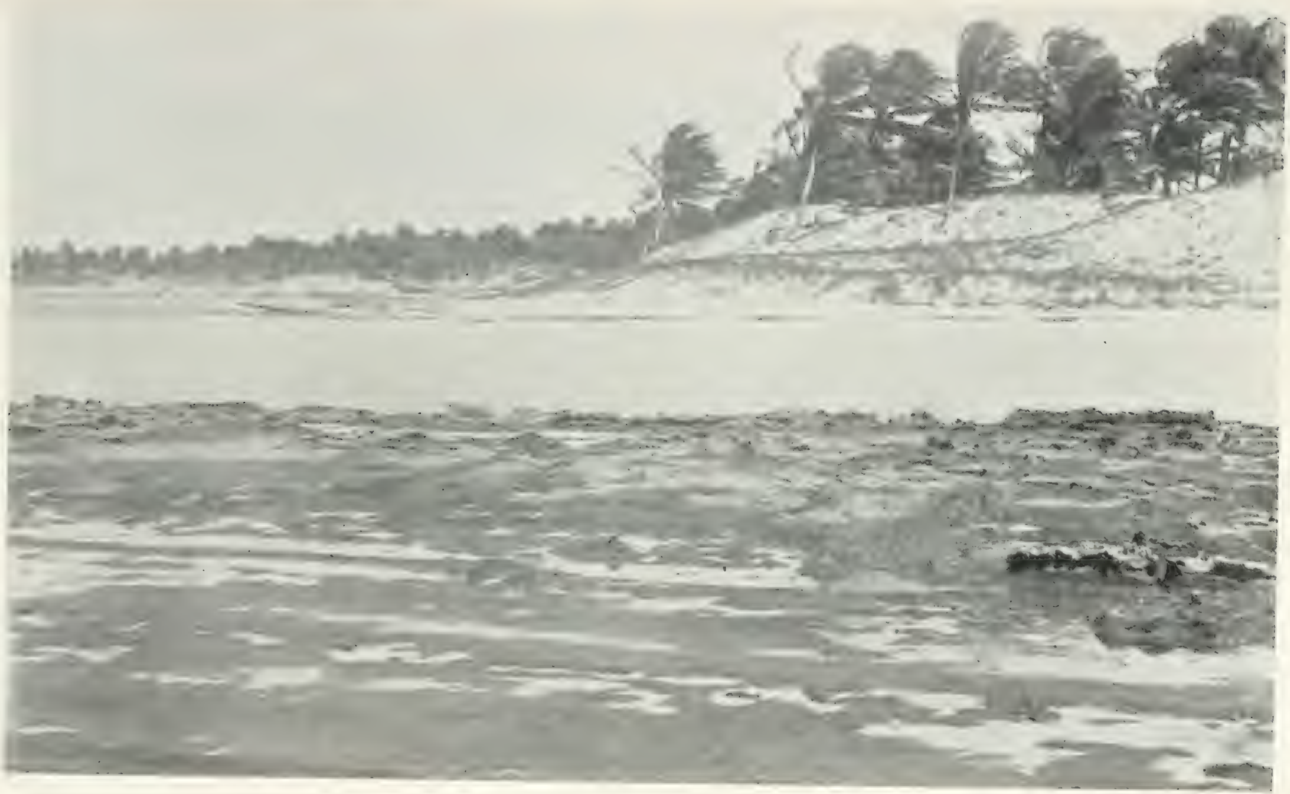
BOULDER-LIKE MASSES OF SAND HELD TOGETHER BY WORMS.



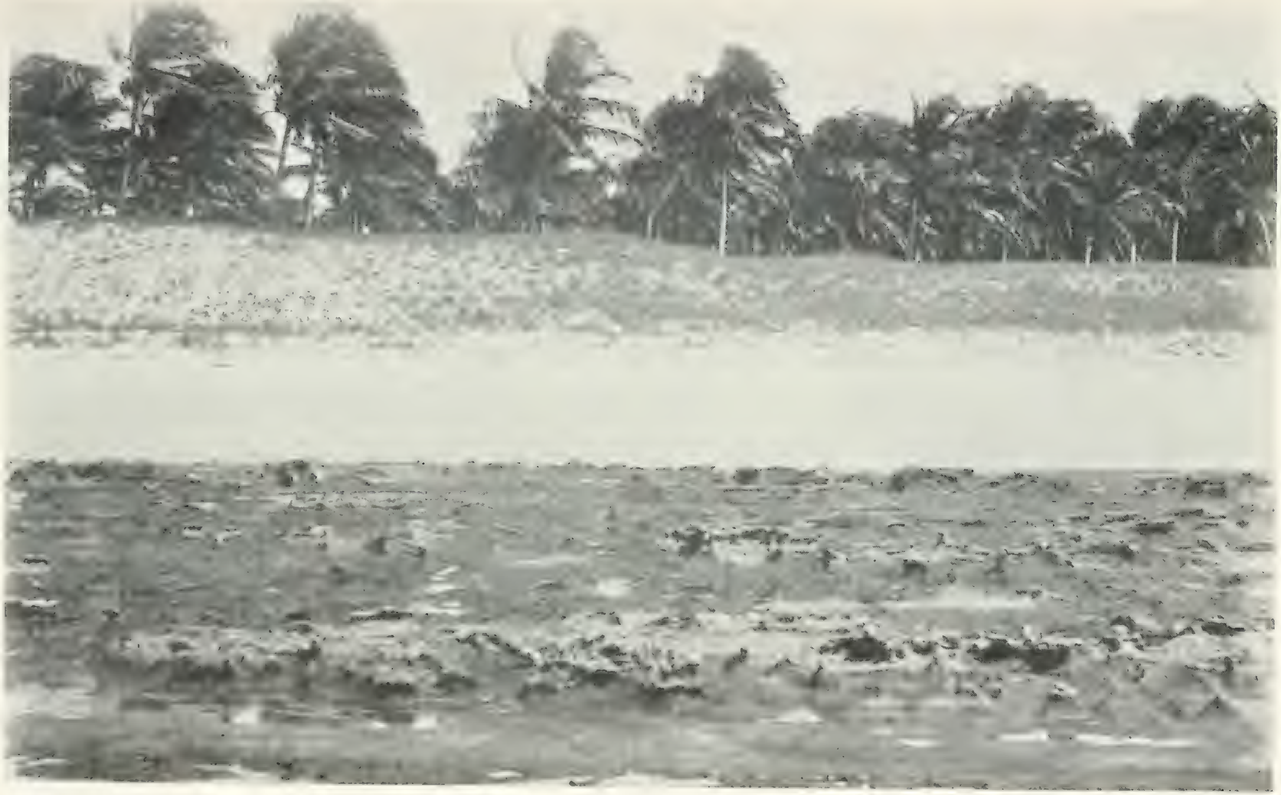
SOUTH END OF THE TRAIÇÃO SANDSTONE REEF.



PART OF THE TRAIÇÃO SANDSTONE REEF.



PART OF THE TRAIÇÃO REEF.



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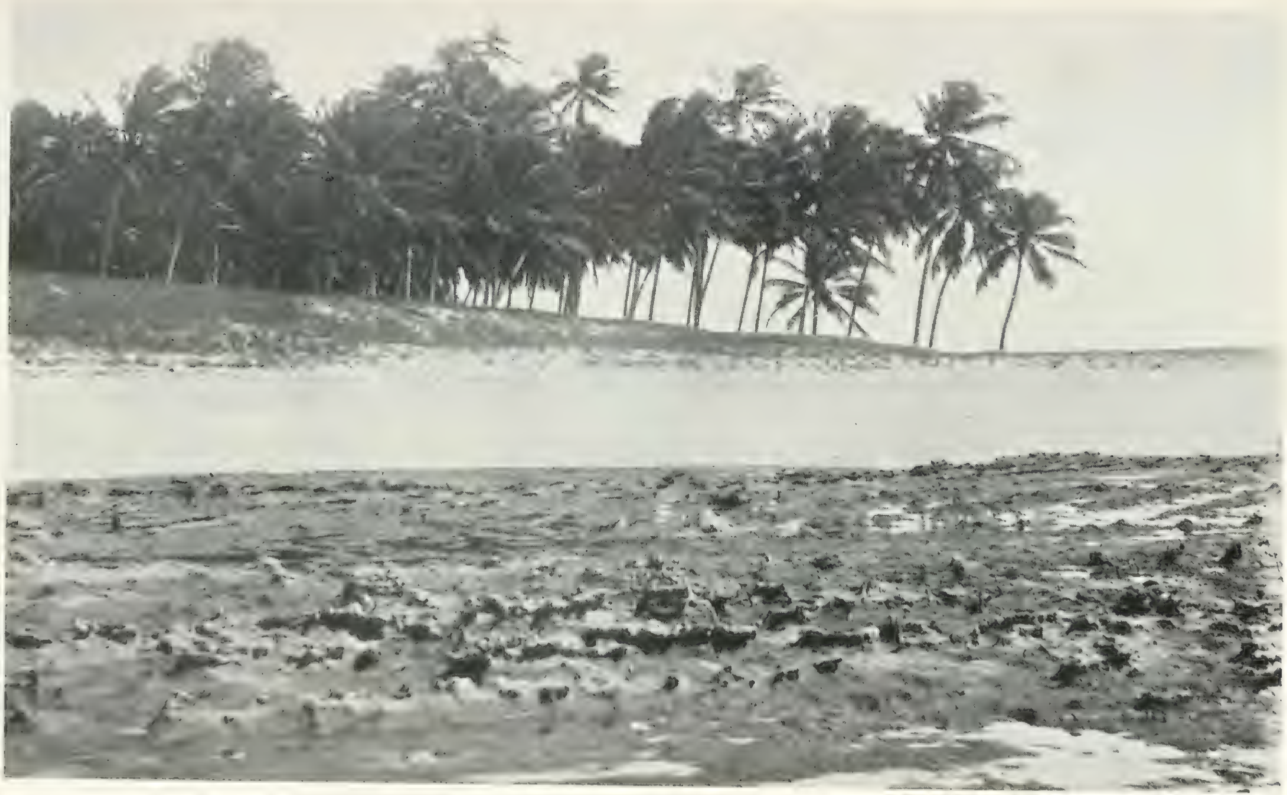

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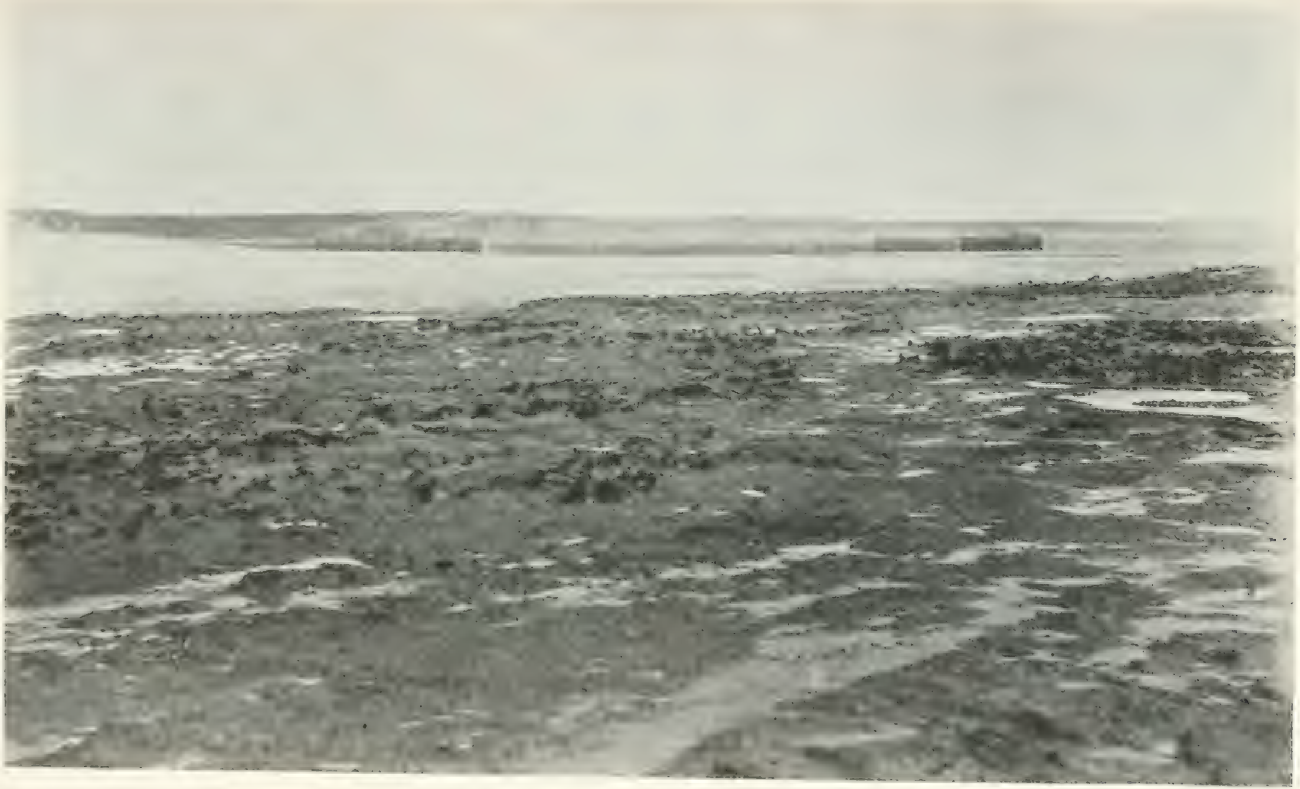
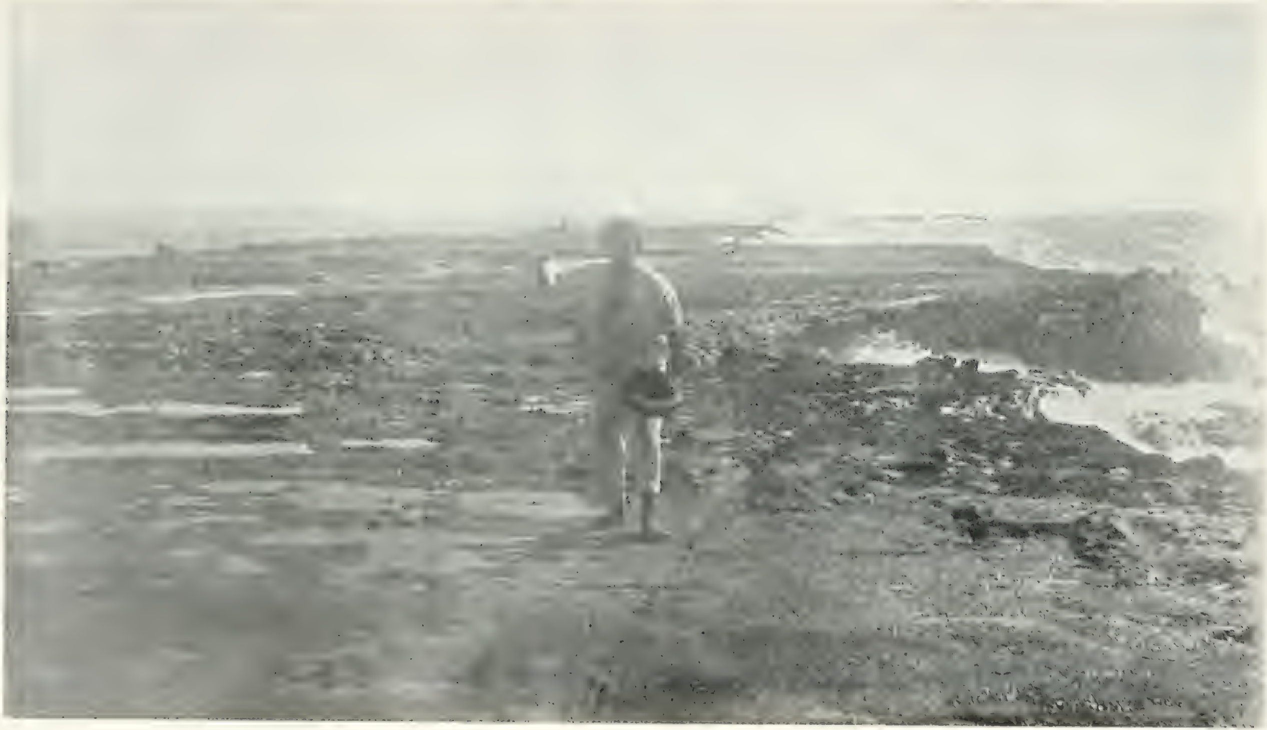
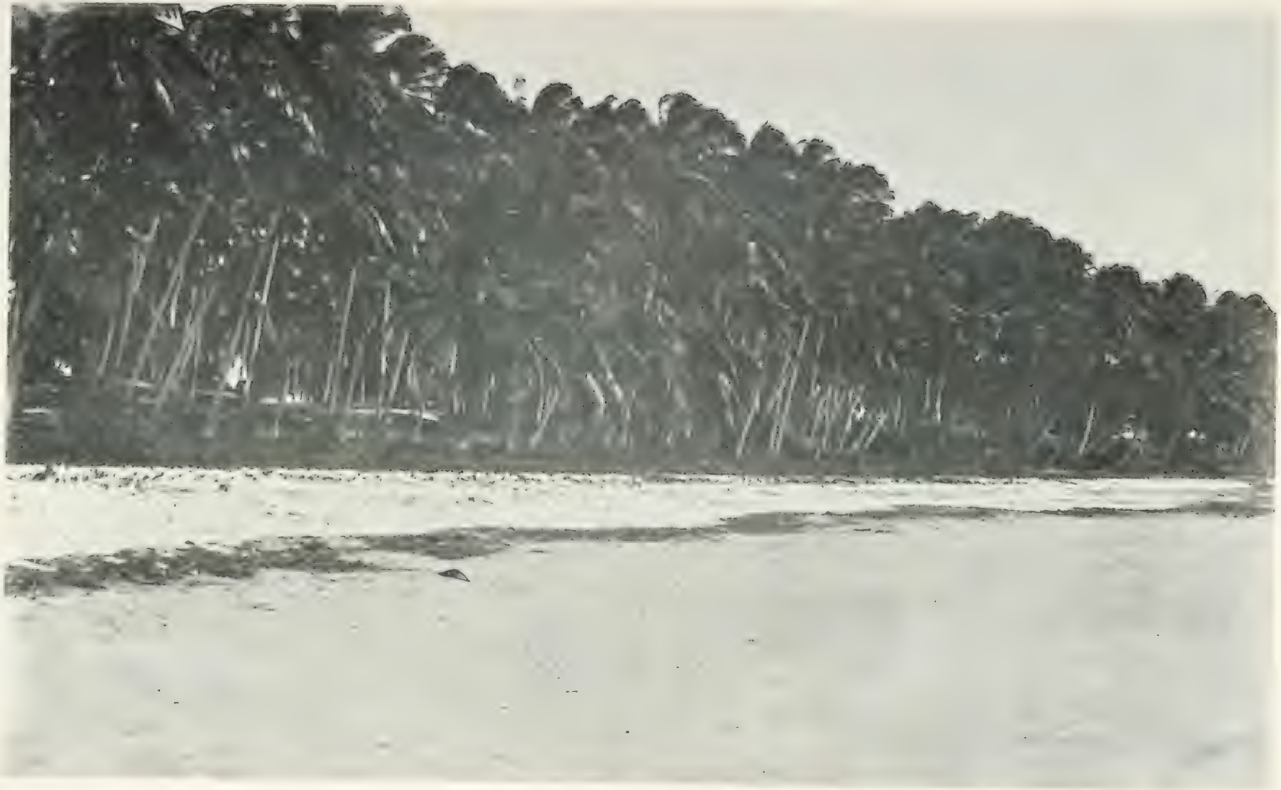


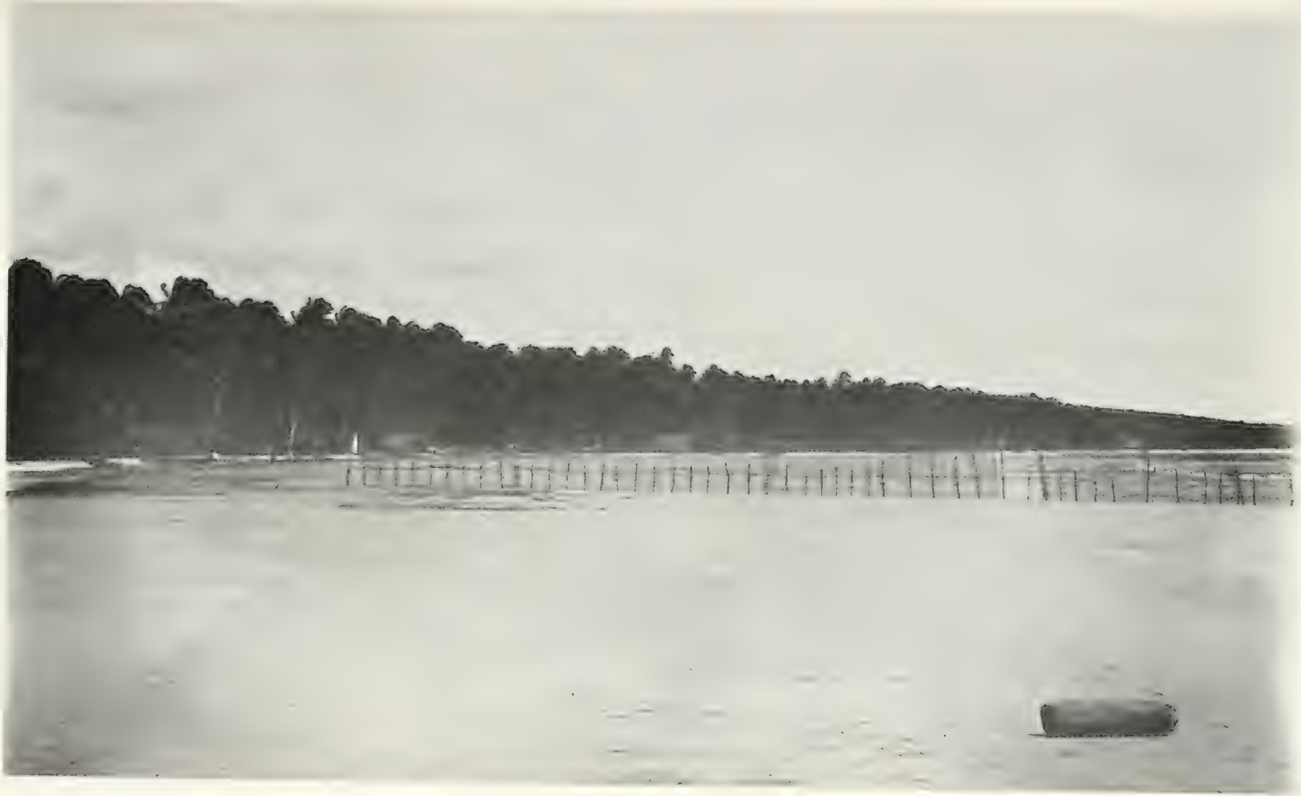
PART OF THE TRAIÇÀO REEF.



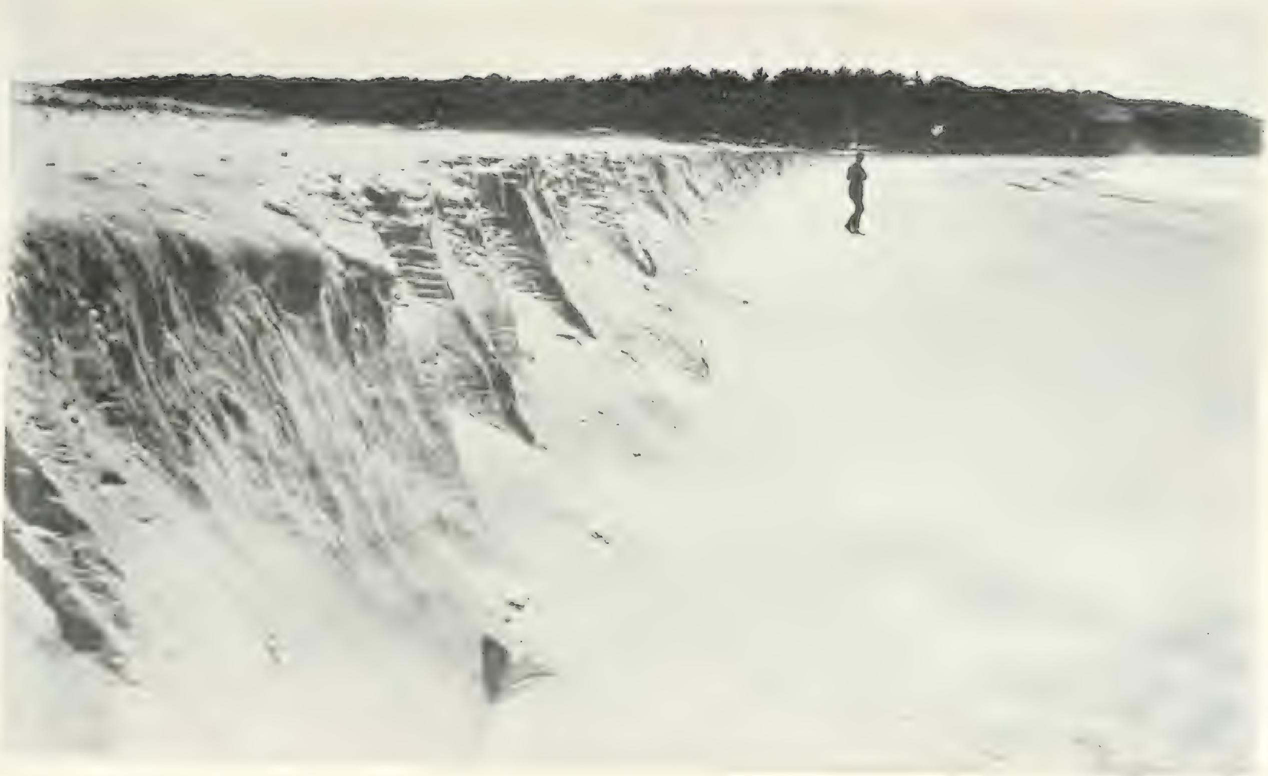
NORTHERN END OF THE TRAIÇÃO SANDSTONE REEF.



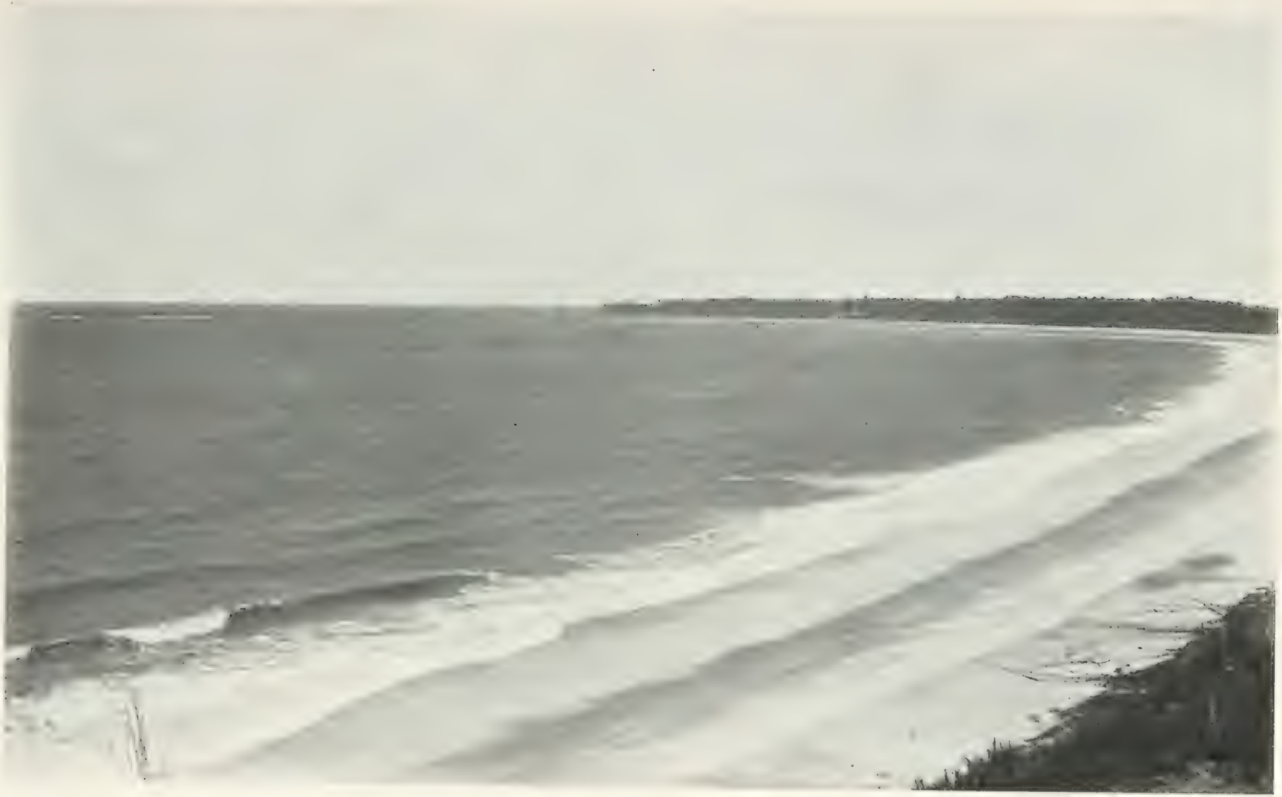
TRAIÇAO STONE REEF.



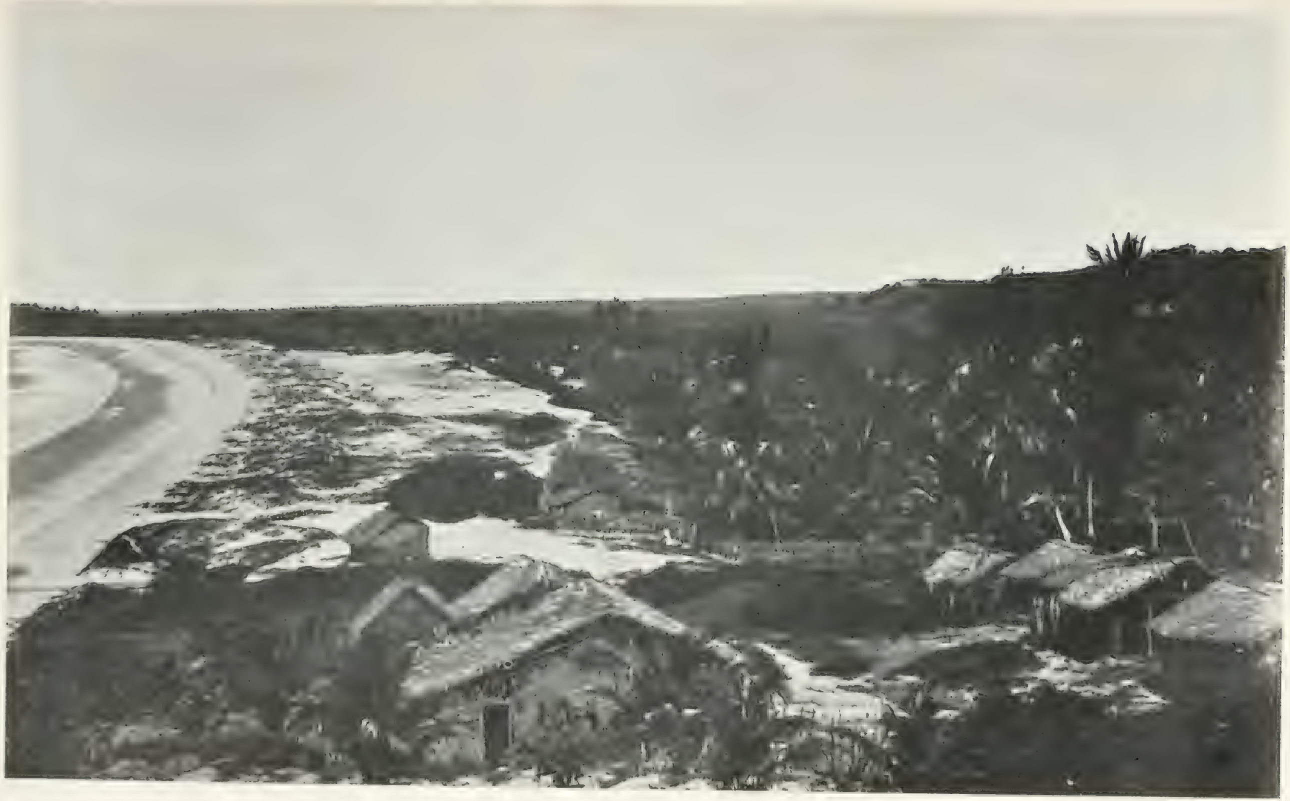
TRAIÇÃO STONE REEF.



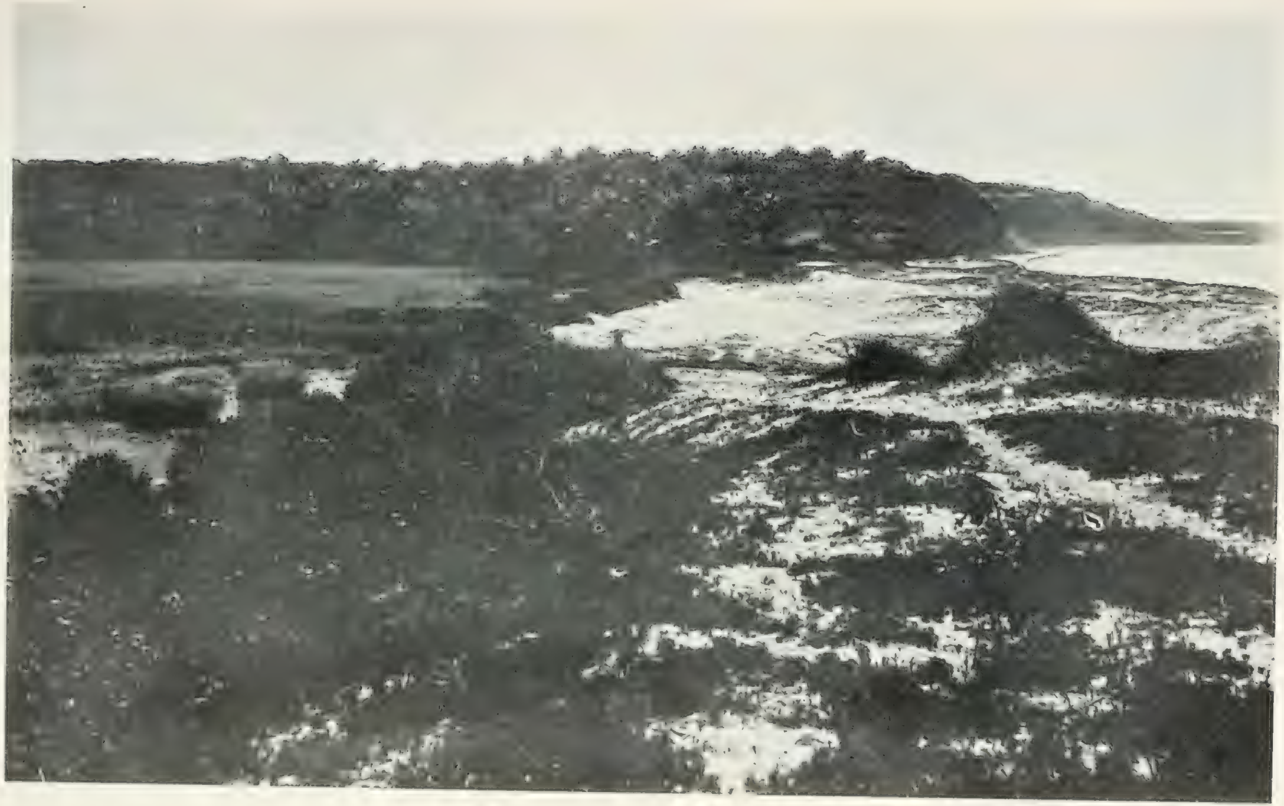
NECK SEPARATING TRAIÇAO BAY FROM LAGOA DE SINIMBÚ.



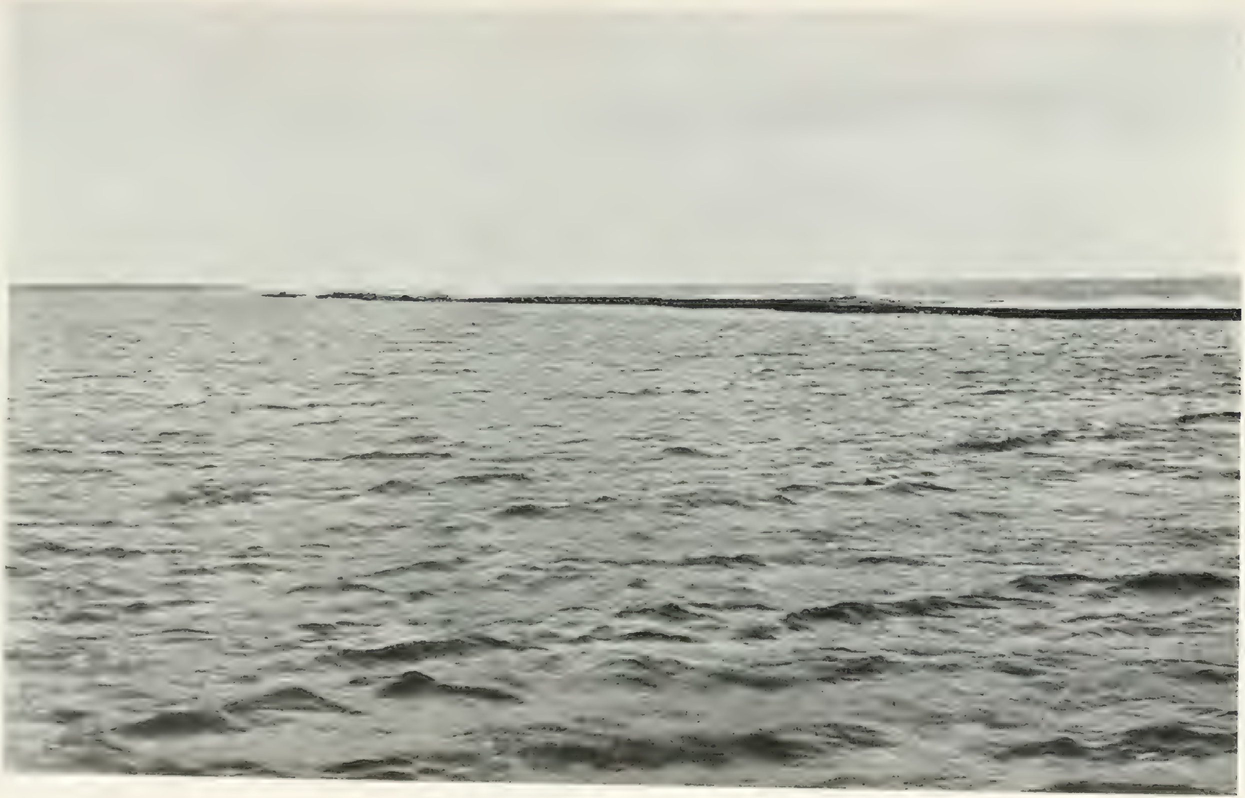
THE NORTHERN END OF TRAIÇÃO STONE REEF.



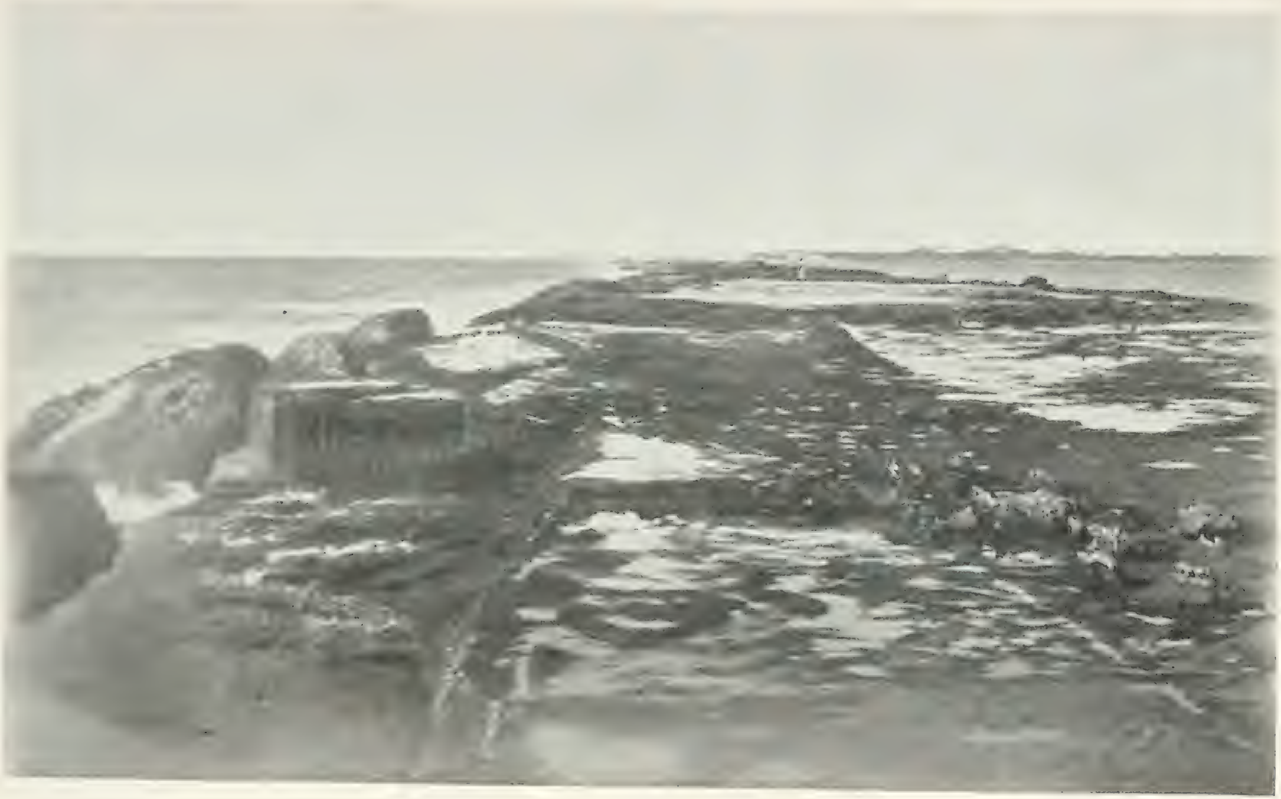
PART OF THE TRAIÇÃO BAY.



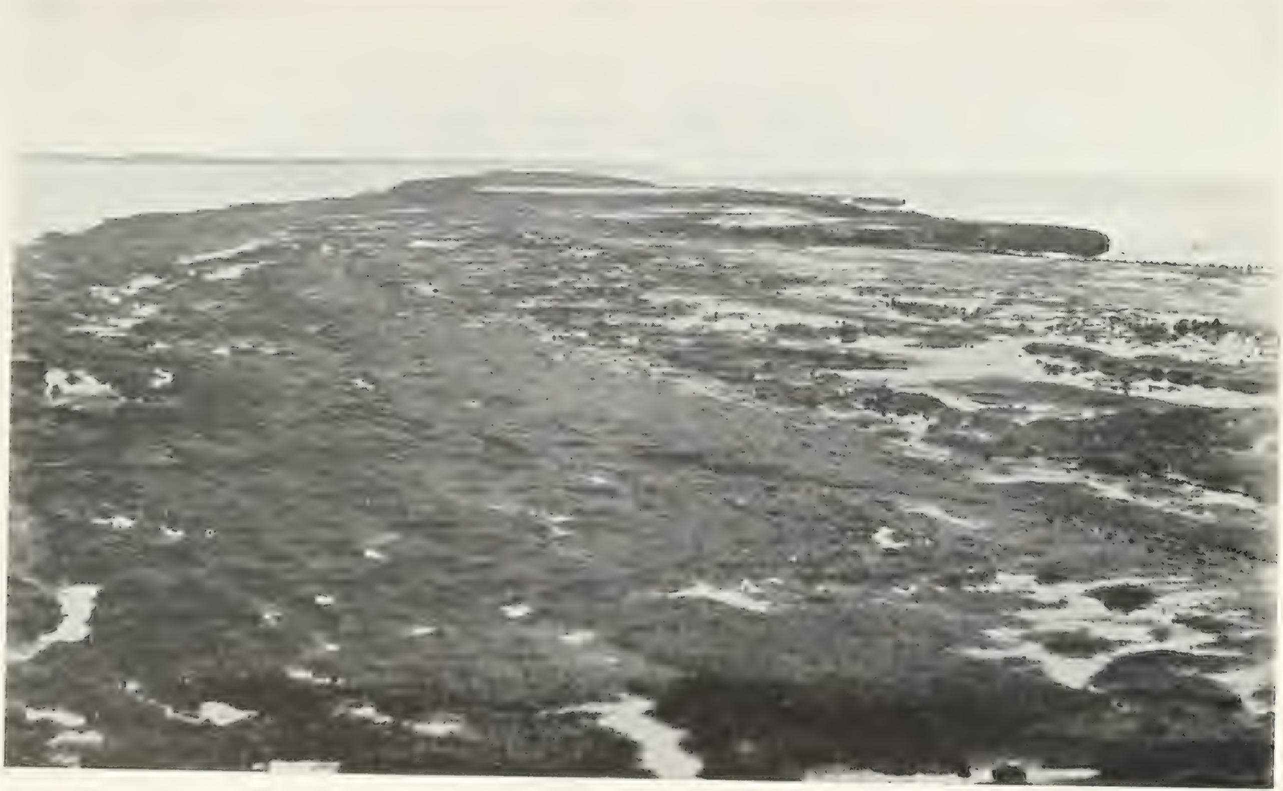
NECK OF SAND BETWEEN TRAIÇÃO AND LAGOA DE SINIMBÚ.



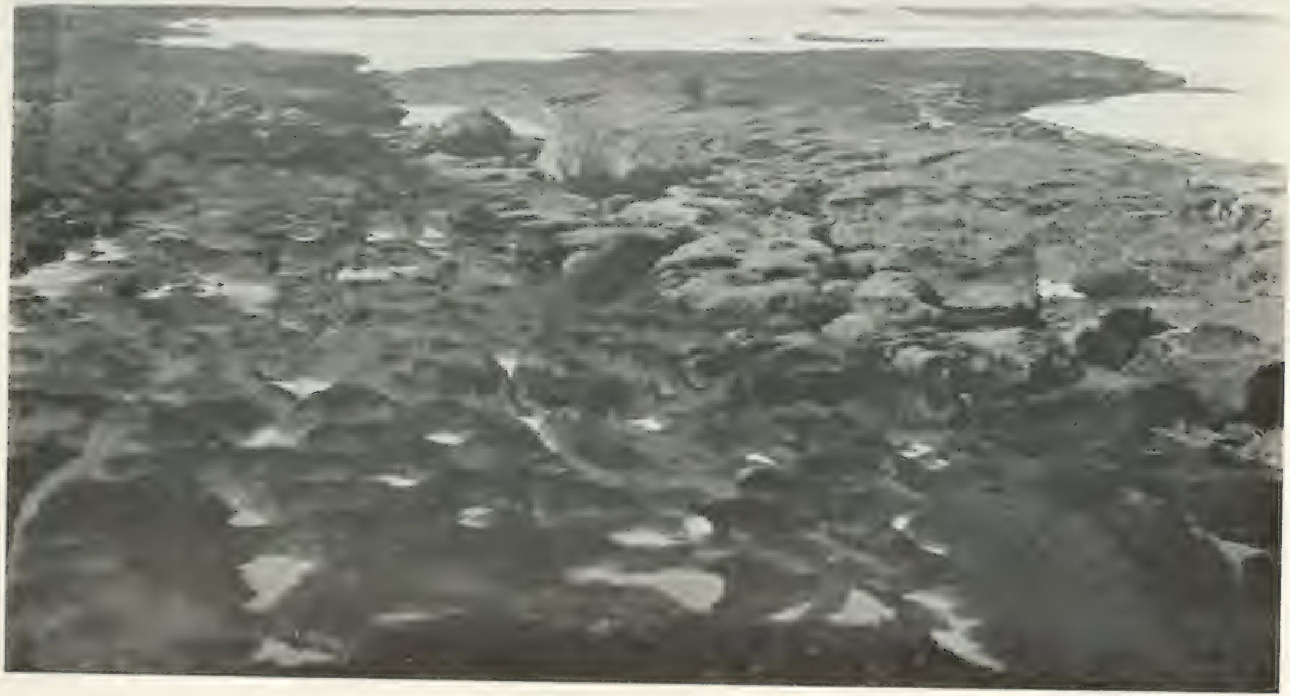
NORTHERN END OF THE MAMANGUÁPE STONE REEF.



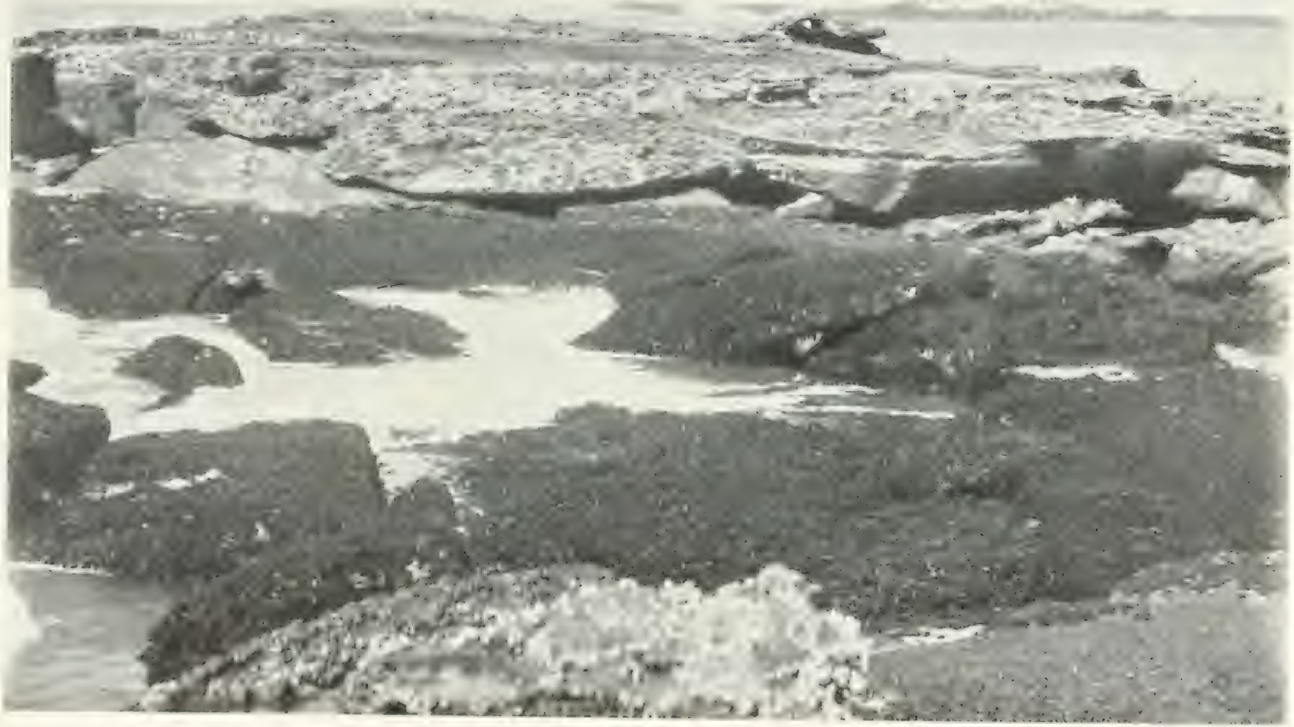
LOOKING SOUTH ALONG THE MAMANGUÁPE SANDSTONE REEF.



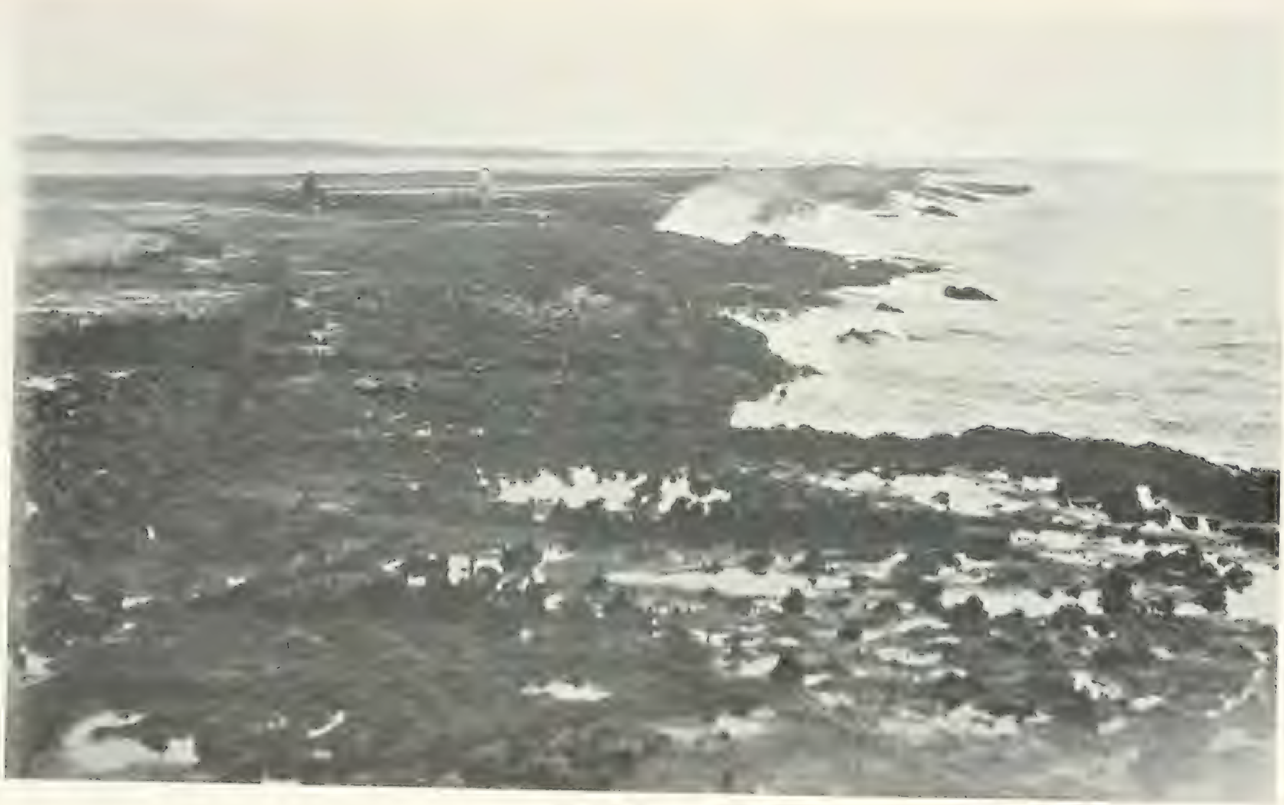
LOOKING NORTH ALONG THE MAMANGUÁPE REEF.



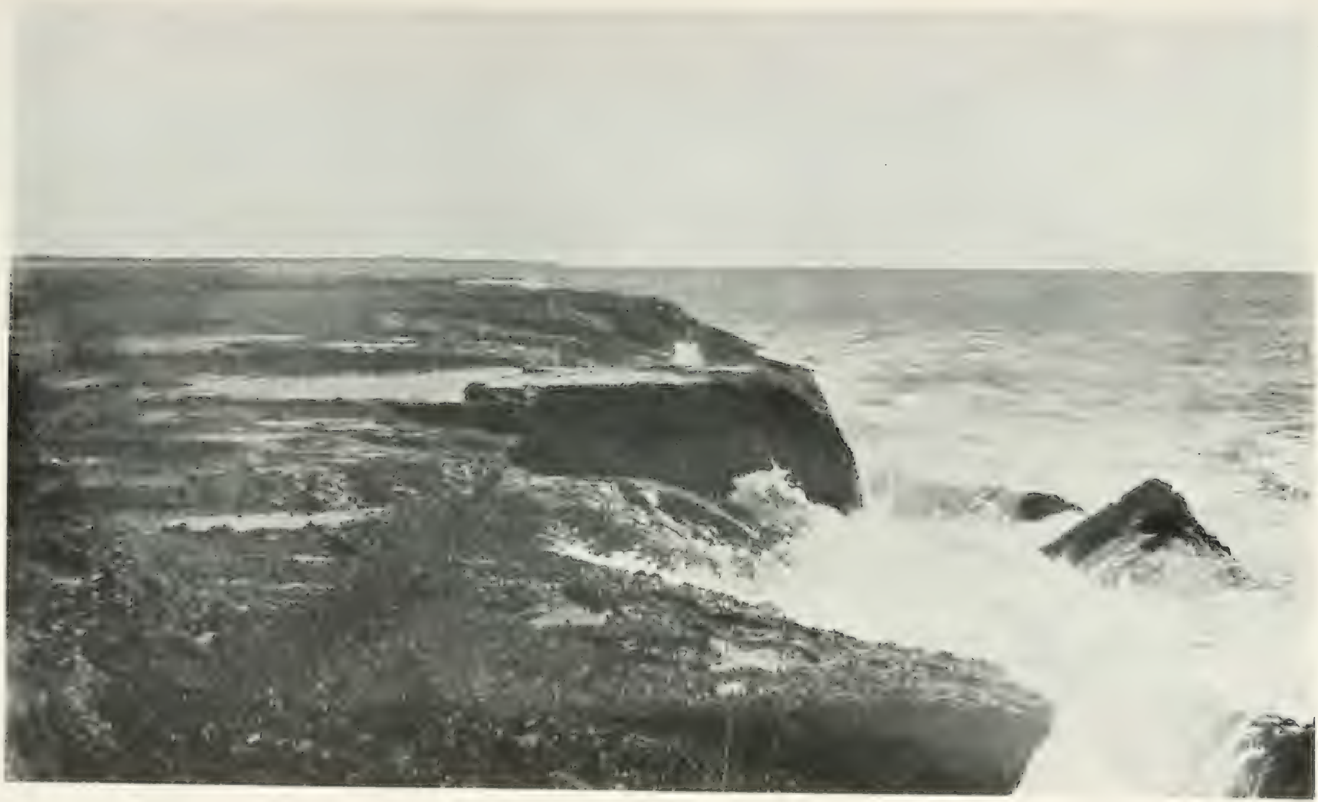
BRANCHING AND BENDING OF THE MAMANGUÁPE REEF.



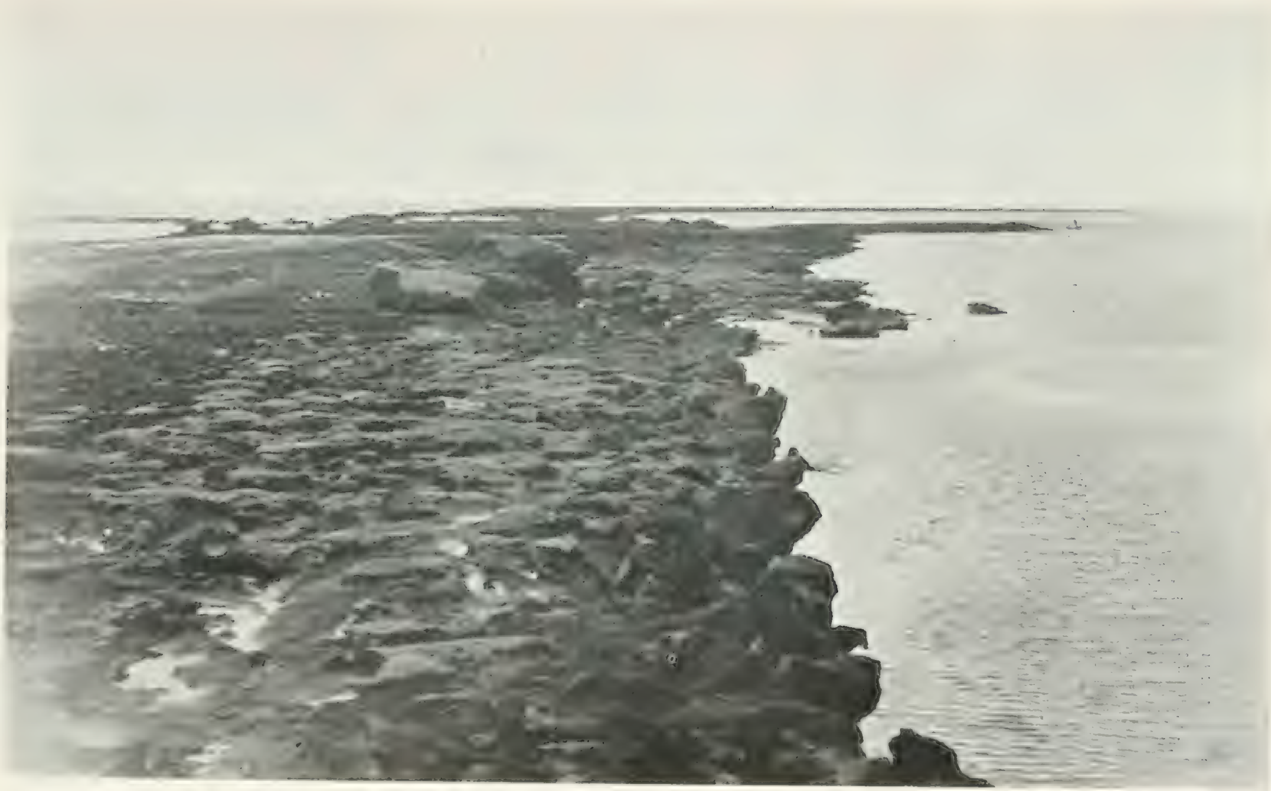
BREAK IN THE MAMANGUÁPE REEF.



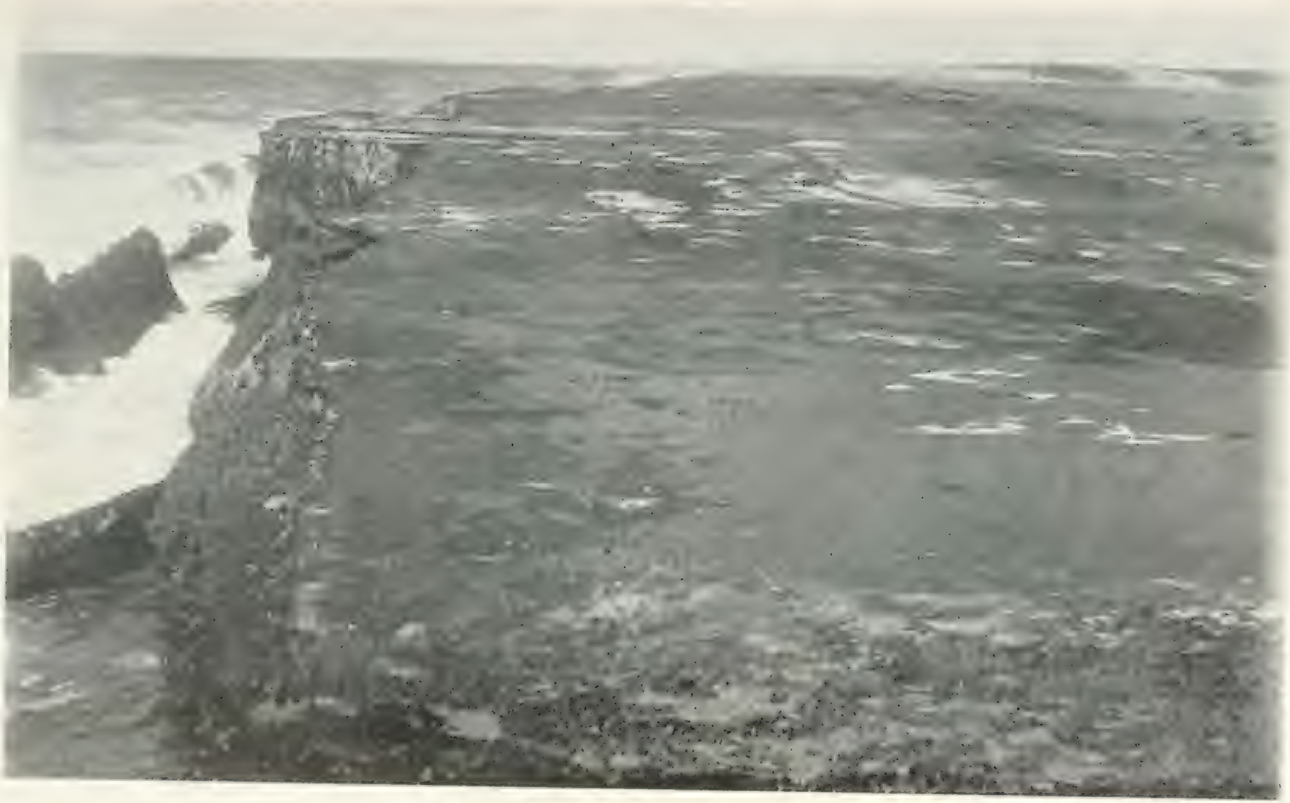
LOOKING NORTHWARD ALONG THE MAMANGUÁPE SANDSTONE REEF.



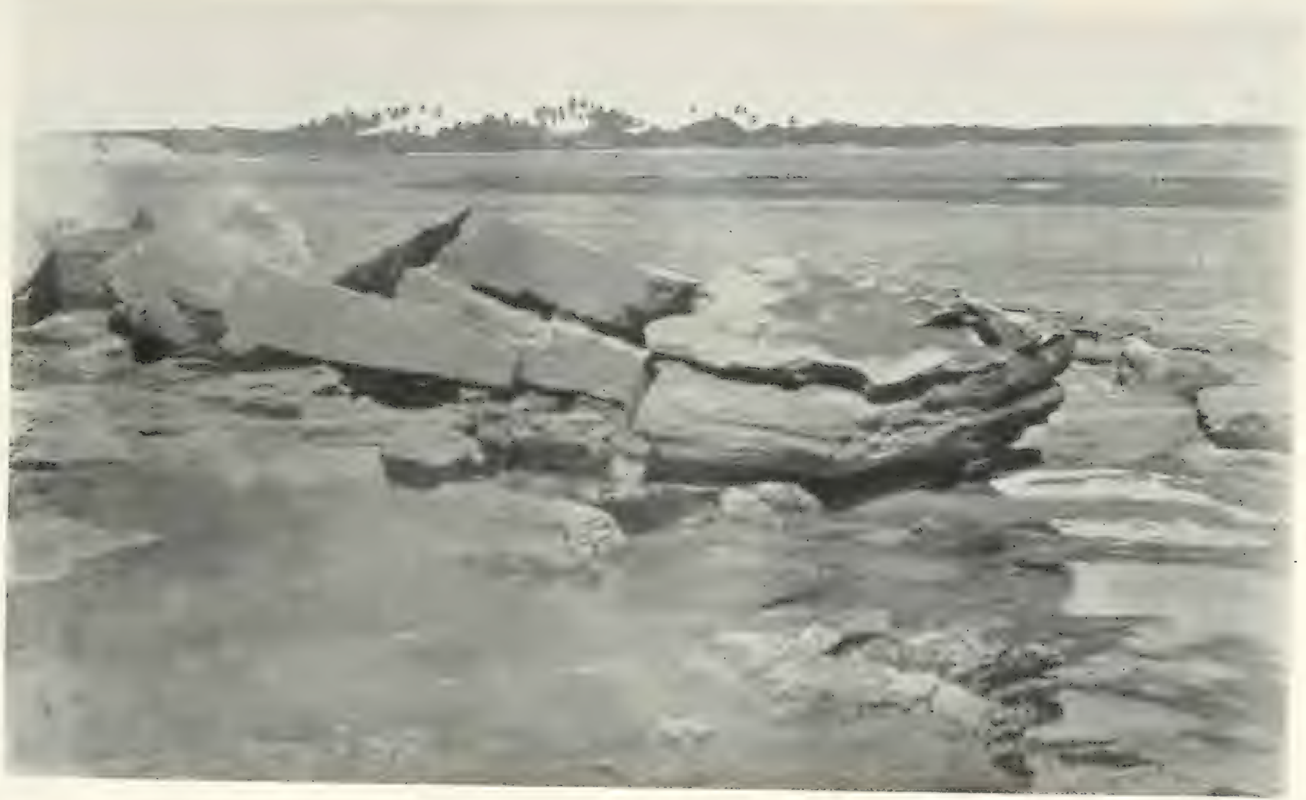
OUTER SIDE OF THE MAMANGUAPE REEF.



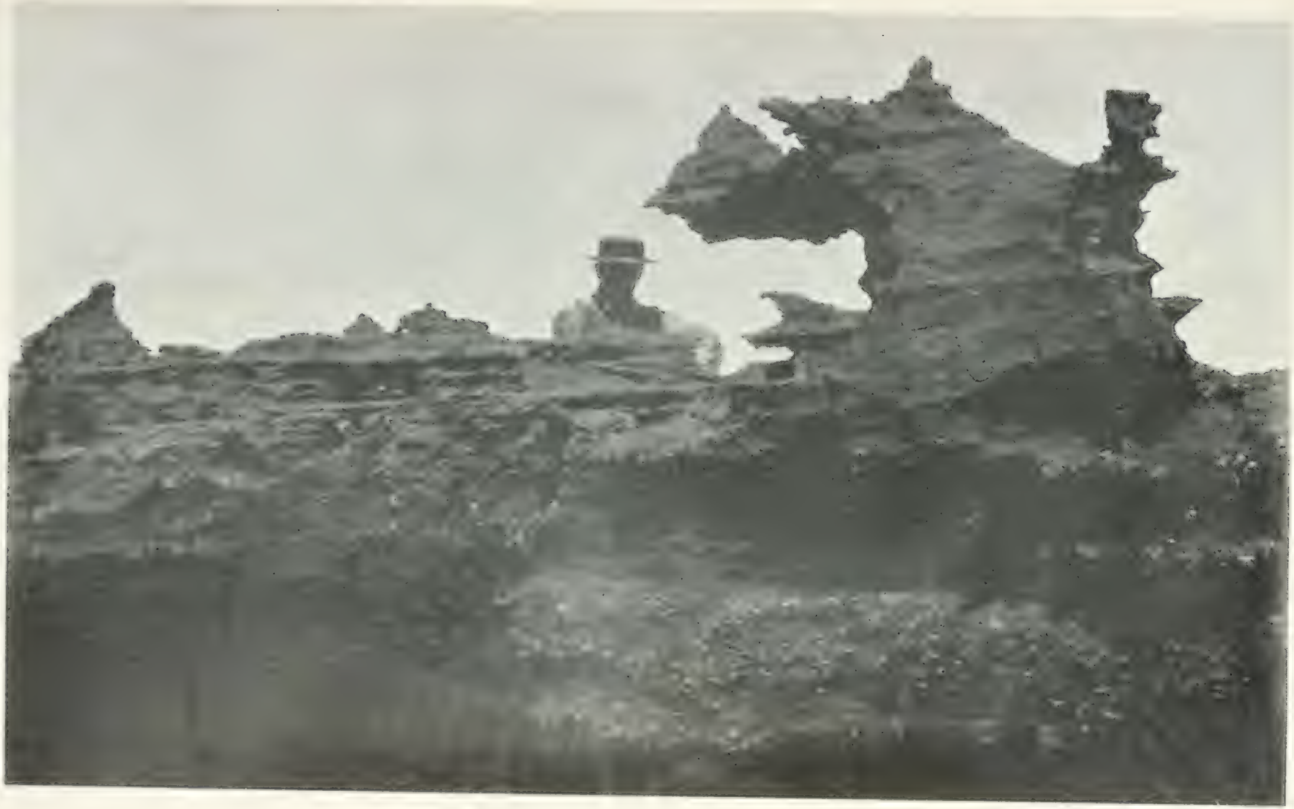
LANDWARD SIDE OF THE MAMANGUAPE REEF.



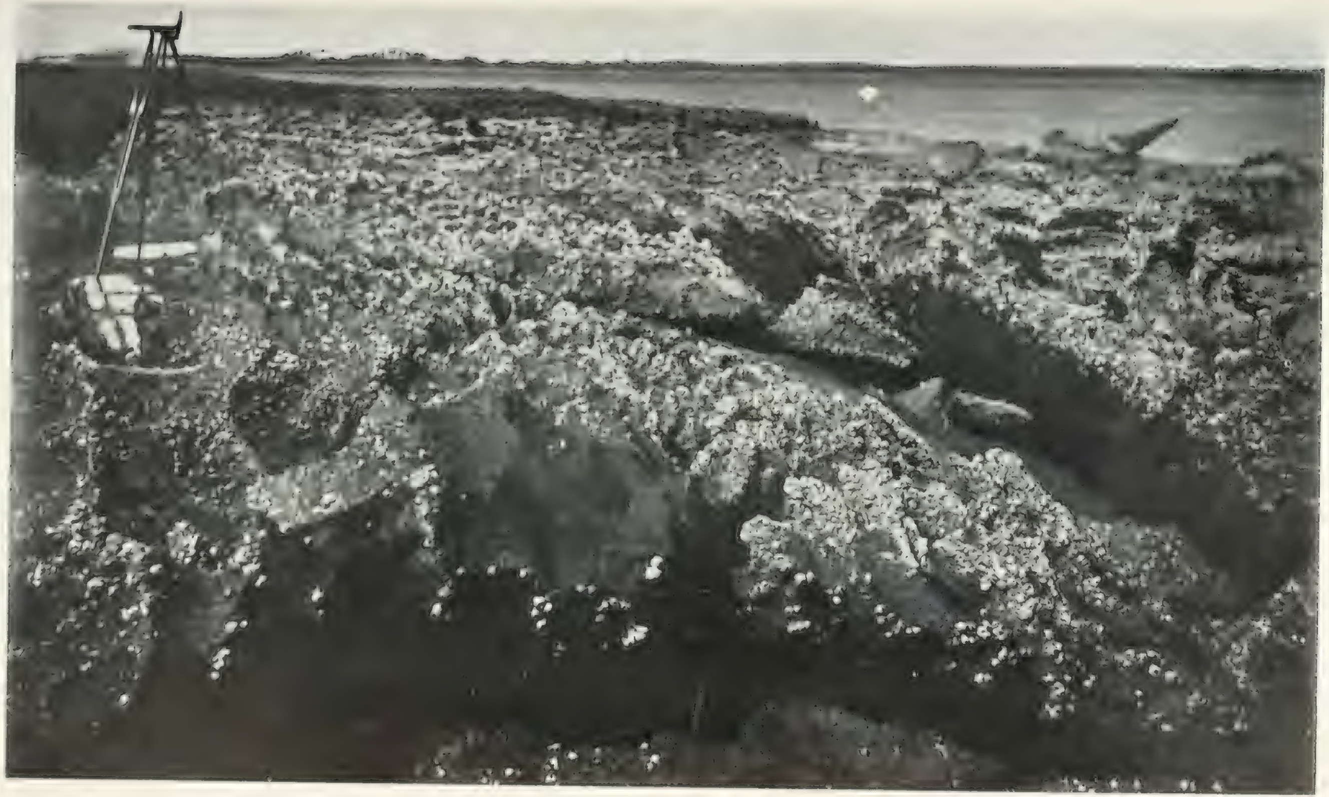
VERTICAL OUTER FACE OF THE MAMANGUÁPE REEF.



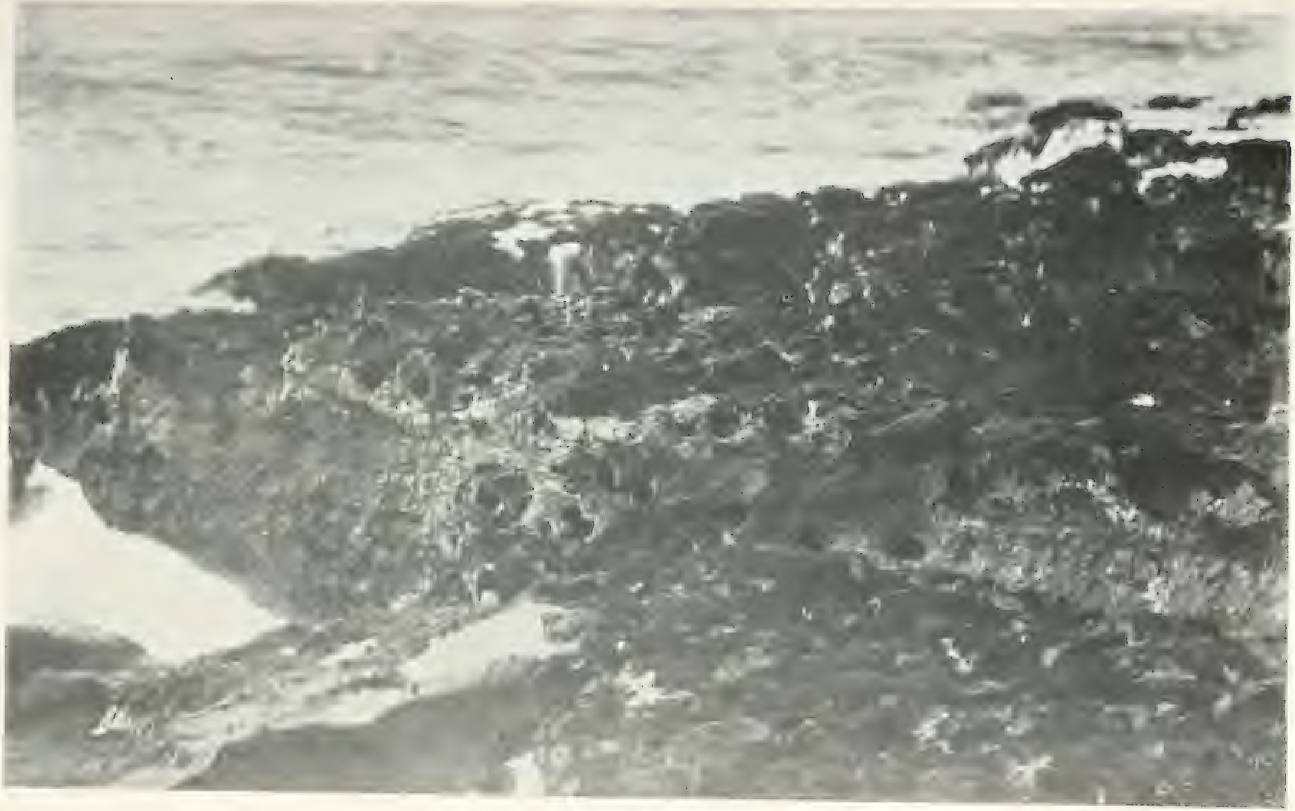
BLOCKS THROWN BY THE SURF ACROSS THE MAMANGUÁPE REEF.



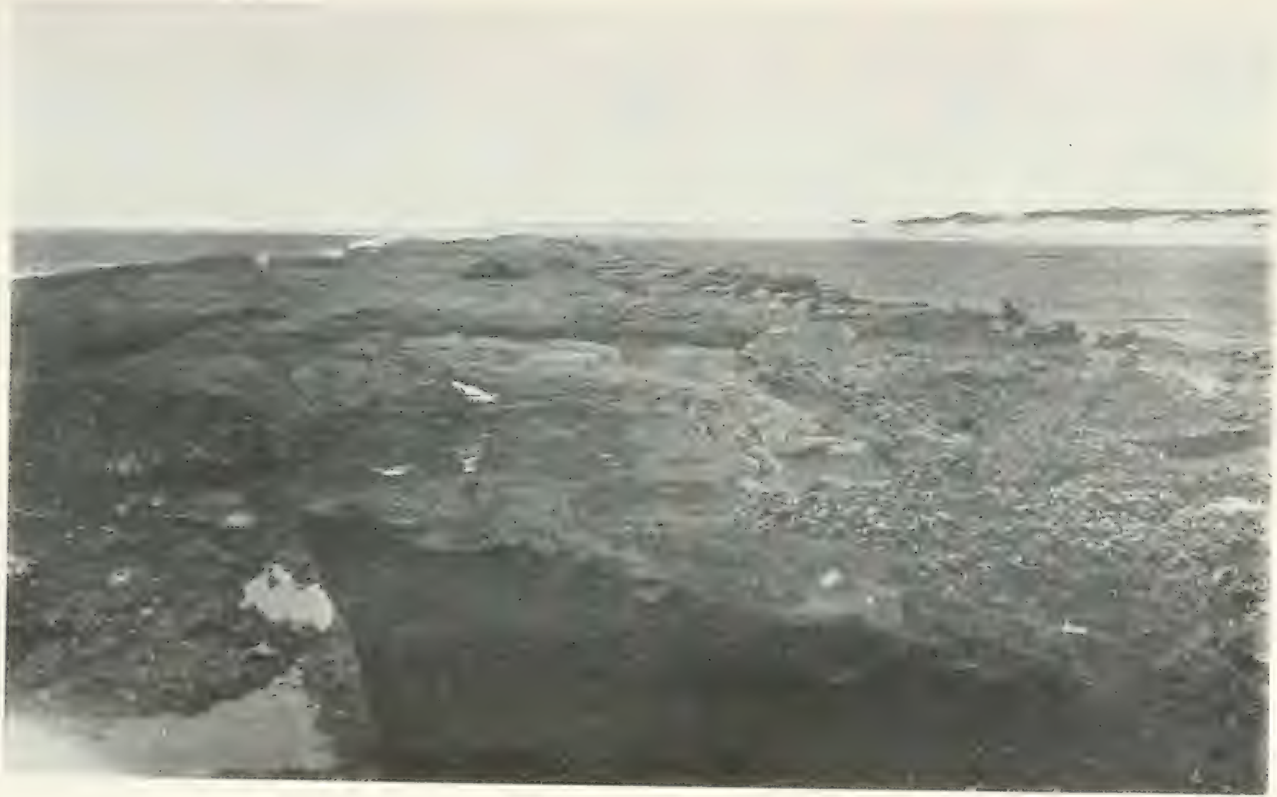
SURFACE ETCHING ON THE MAMANGUAPE REEF.



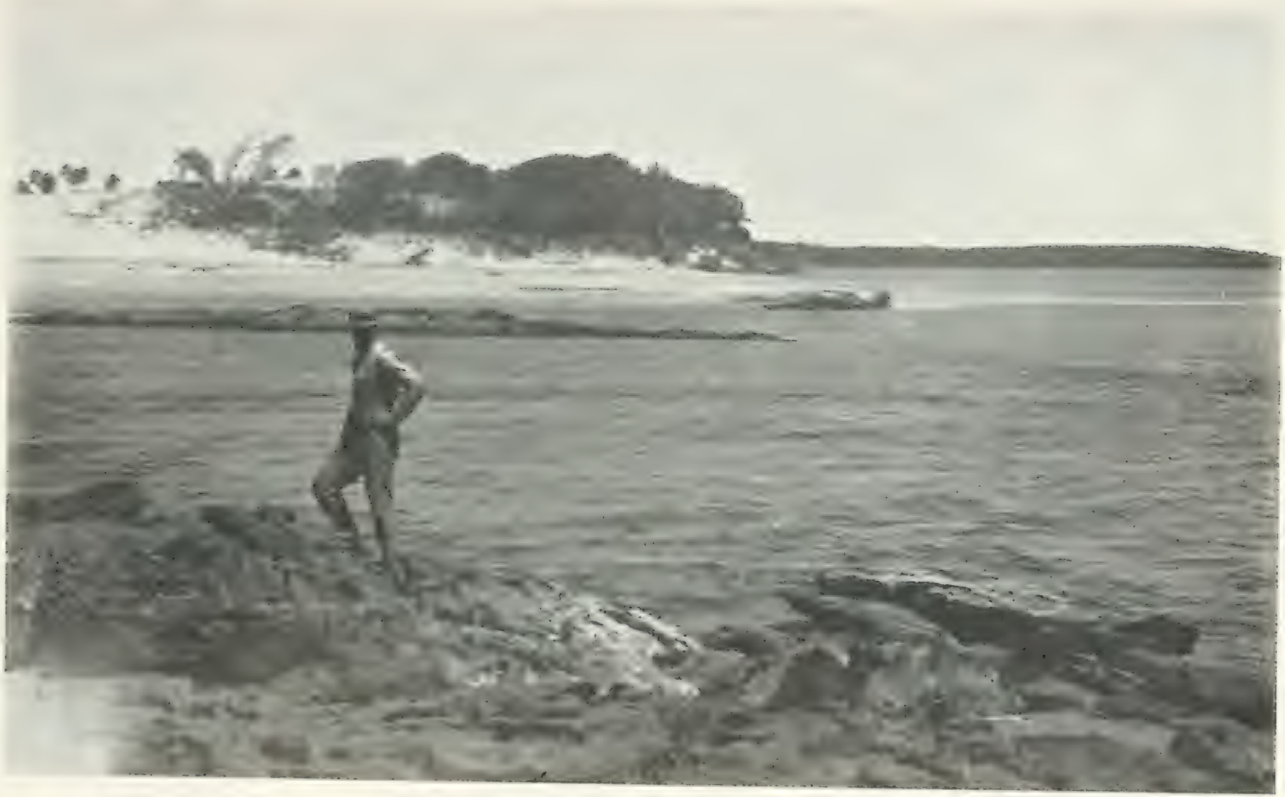
ERODED SURFACE OF THE MAMANGUÁPE REEF.



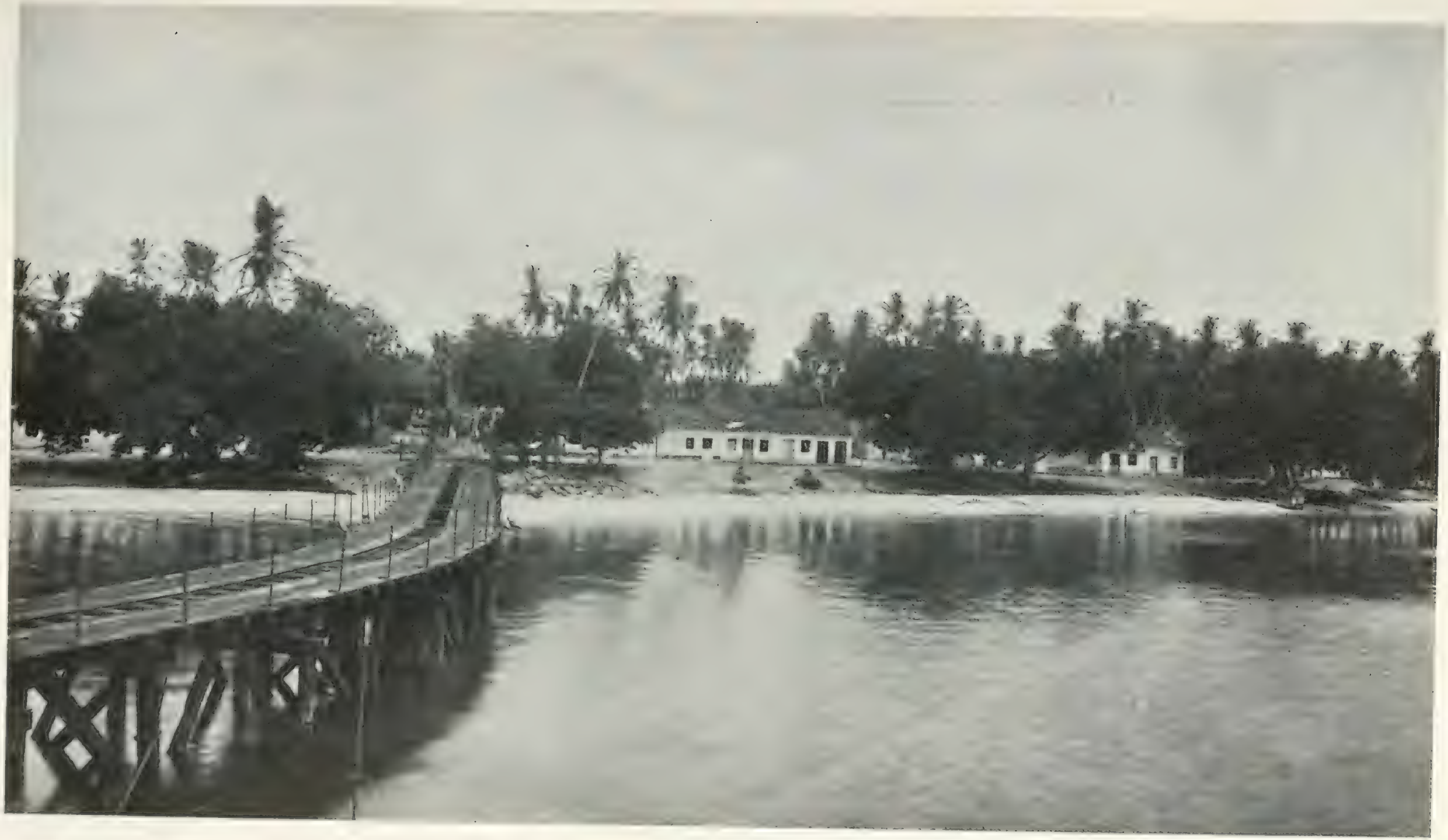
SEA-URCHIN HOLES IN THE MAMANGUÁPE REEF.



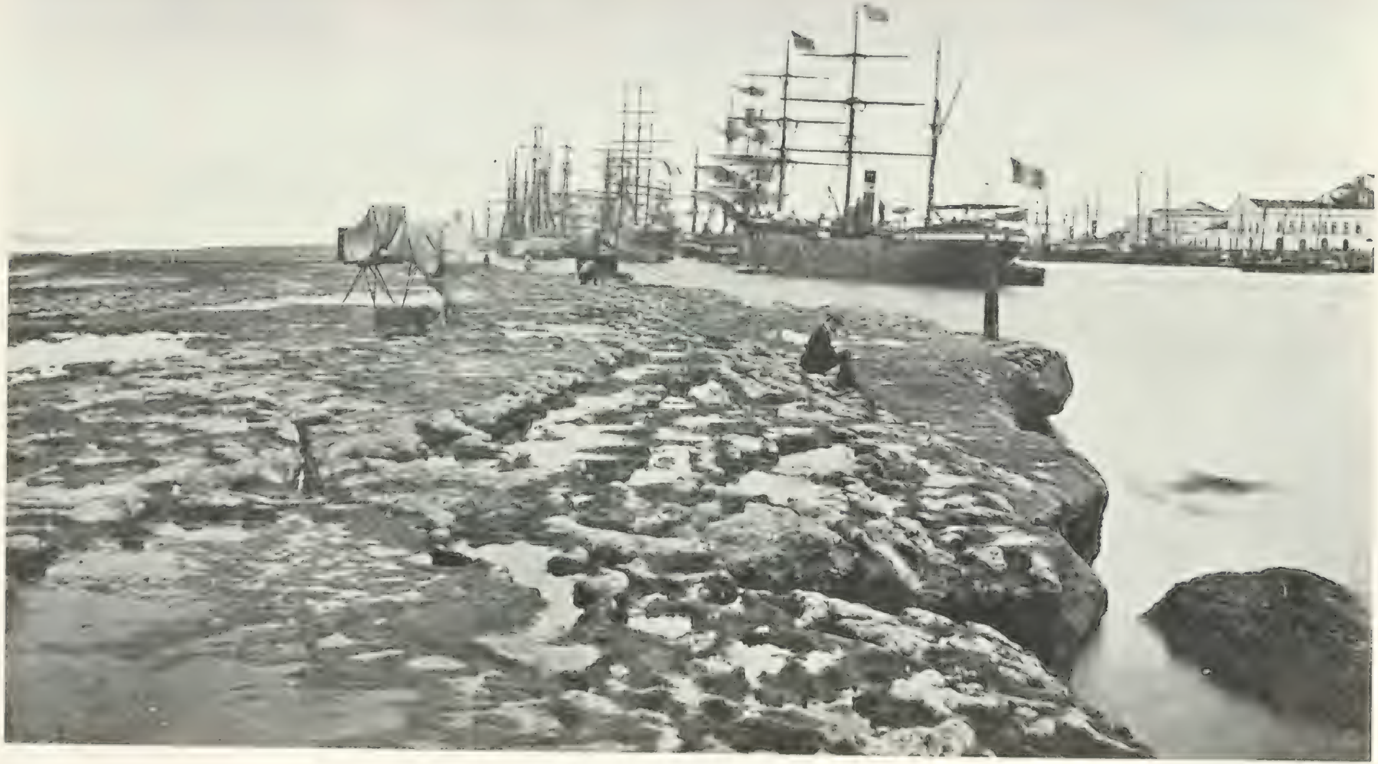
THE SOUTHERN END OF THE MAMANGUÁPE REEF.



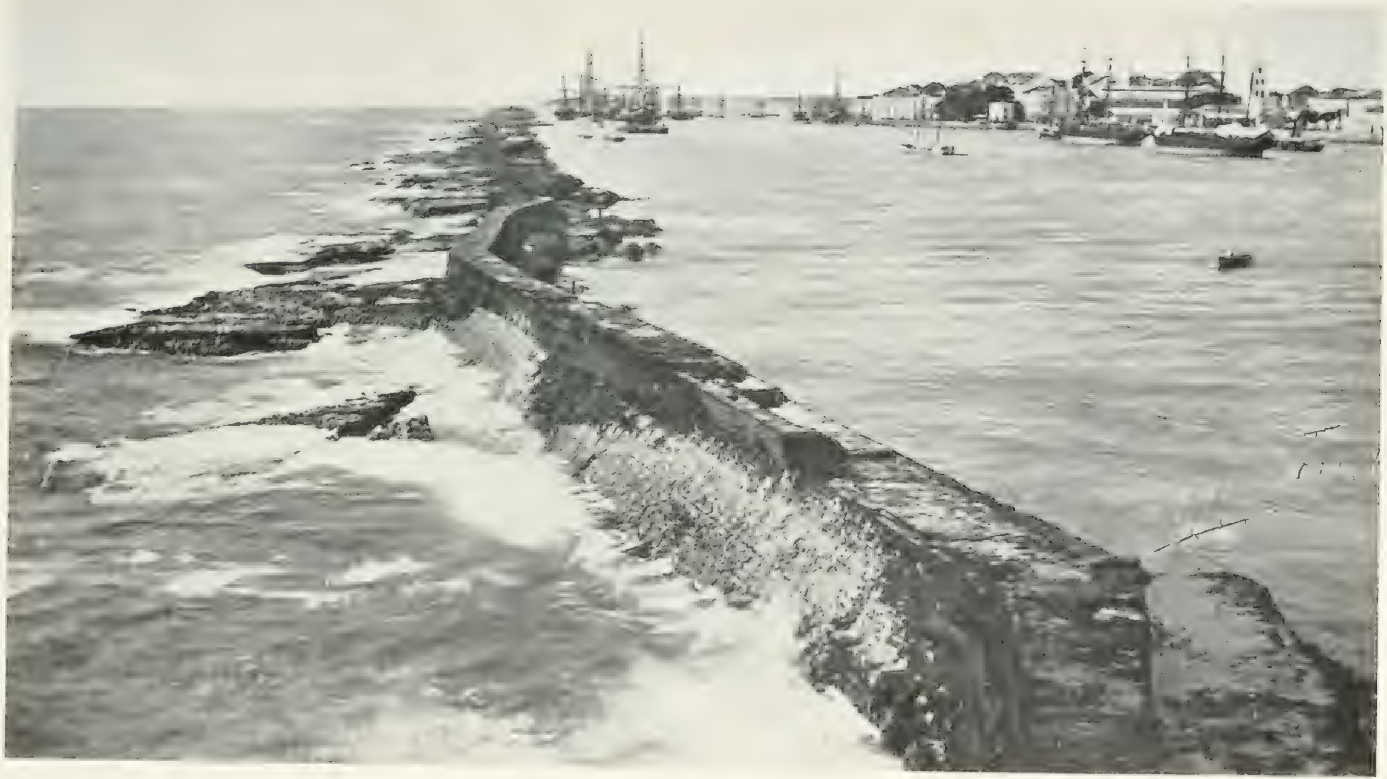
MAMANGUAPE POINT.



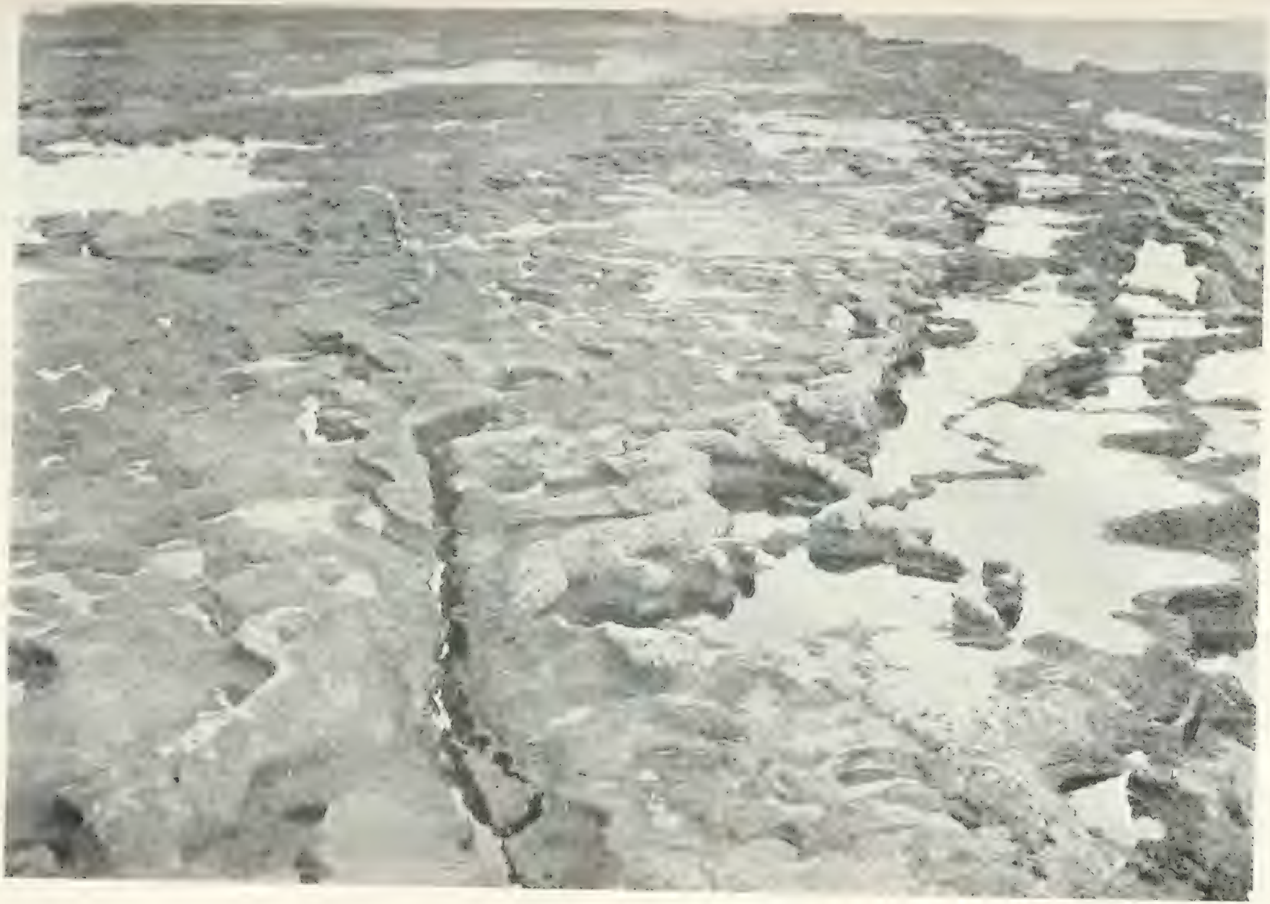
THE SAND PLAINS AT CABEDELLO, PARAHYBA DO NORTE.



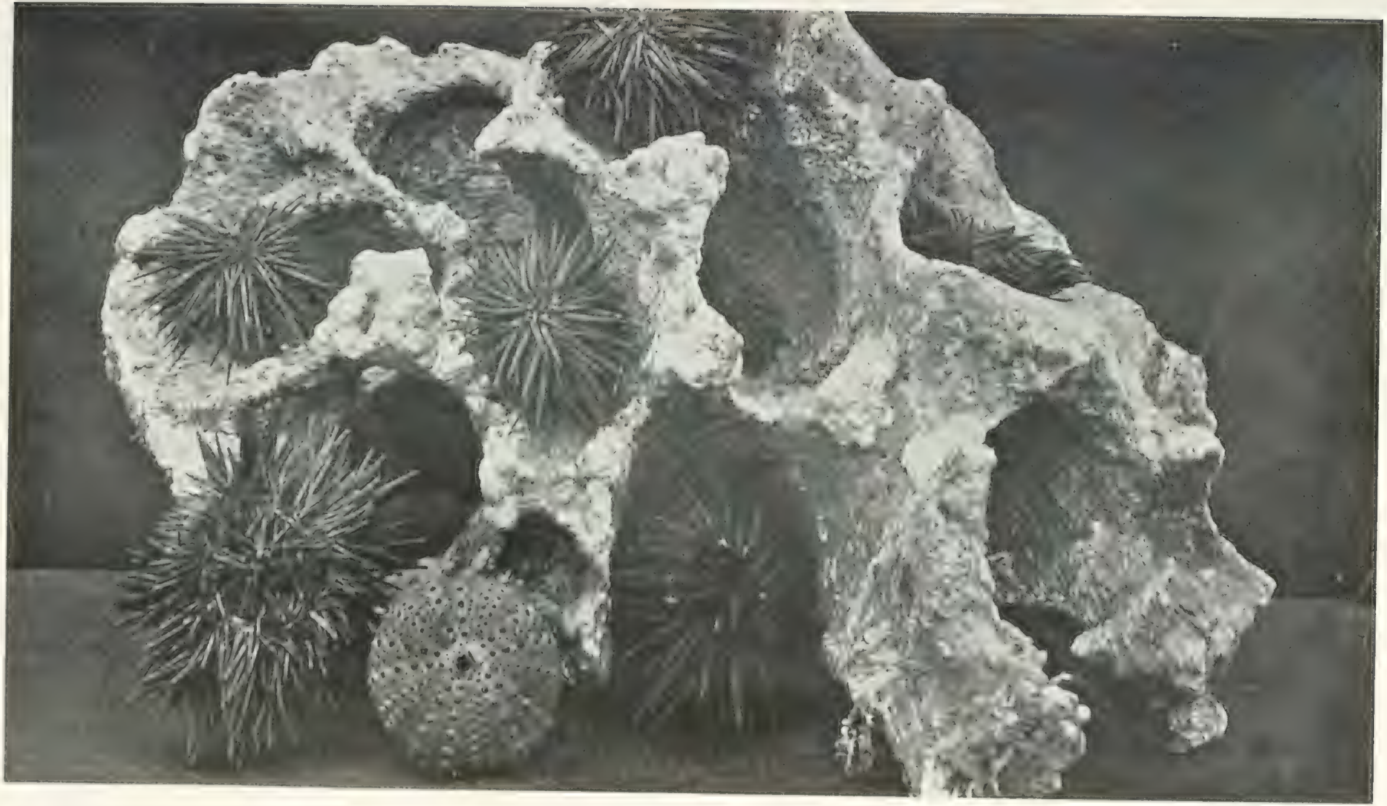
PERNAMBUCO STONE REEF.



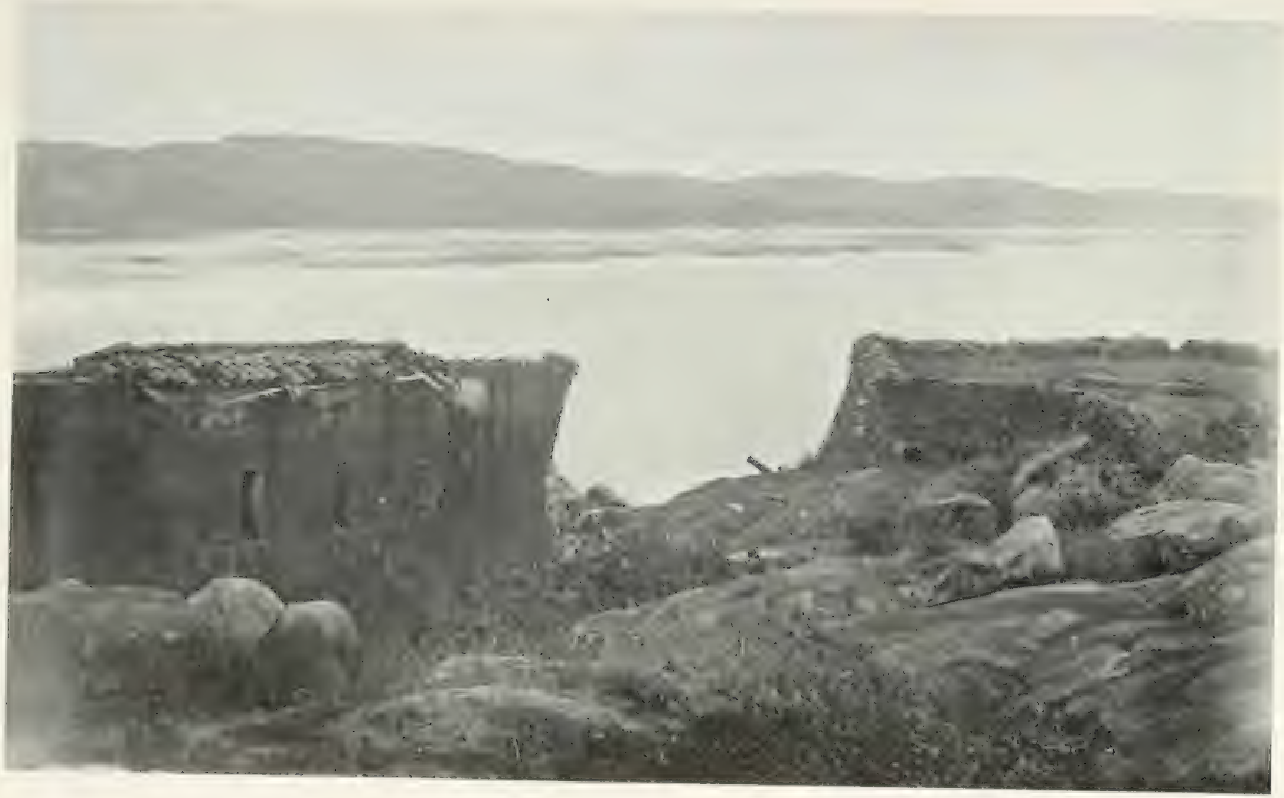
PERNAMBUCO REEF, FROM THE OLD DUTCH FORT.



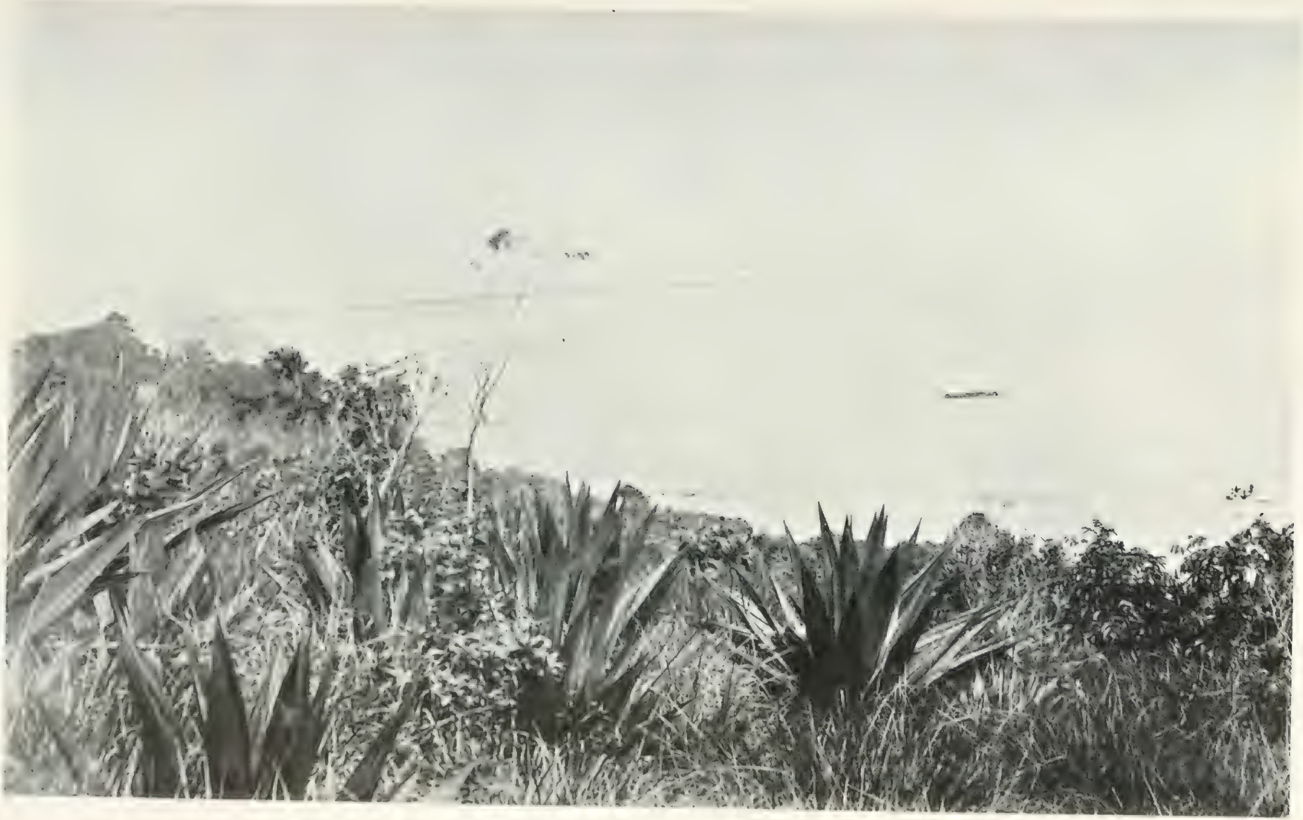
SURFACE OF THE PERNAMBUCO REEF.



PERNAMBUCO REEF ROCK.

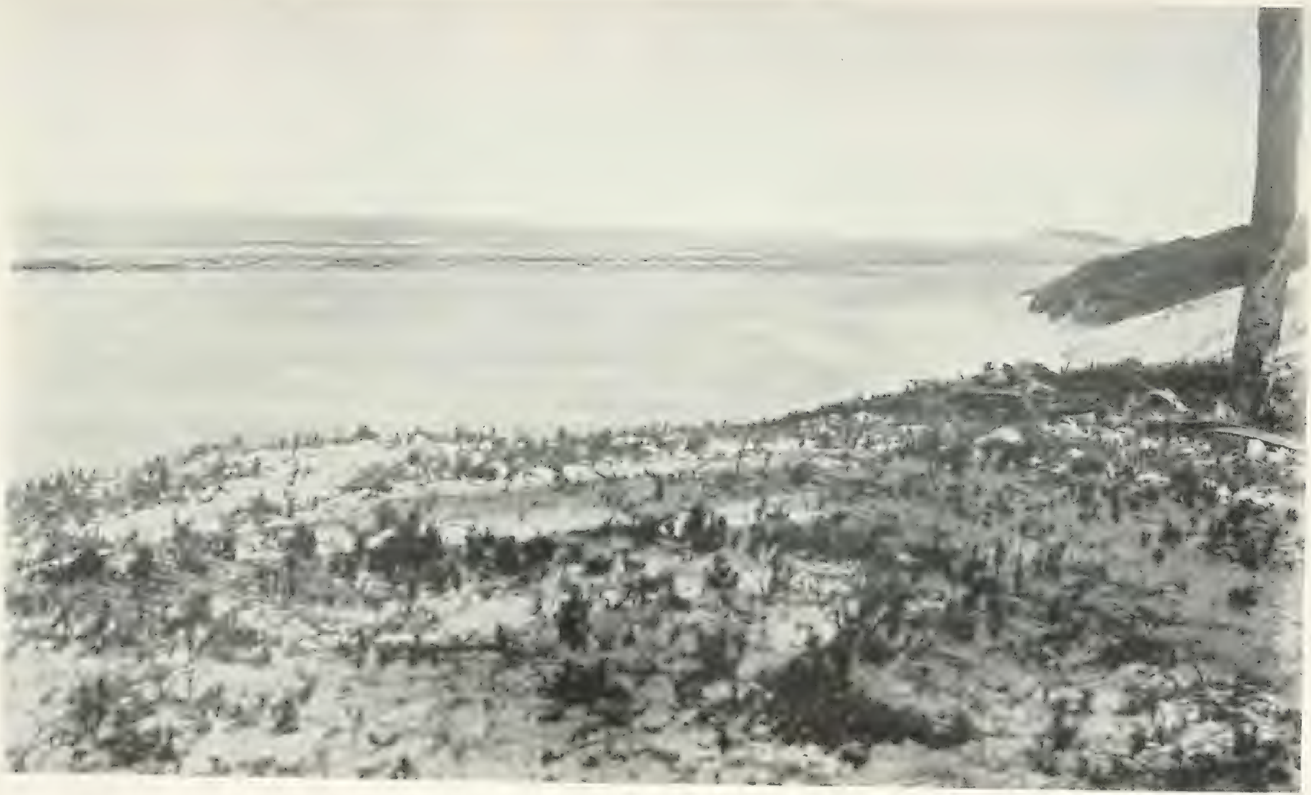


THE SANDSTONE REEF, NORTH OF GAIBÚ.

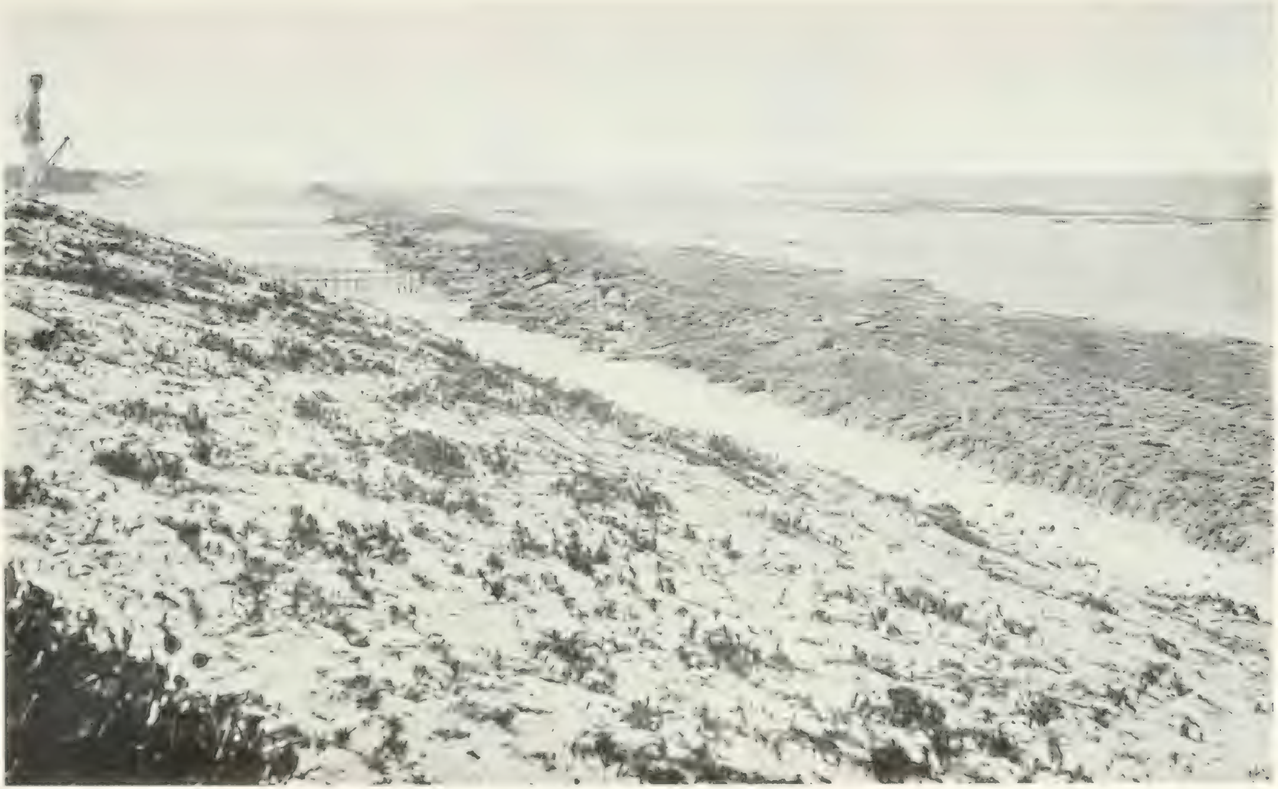


THE SANDSTONE REEF SOUTH FROM CABO SANTO AGOSTINHO.

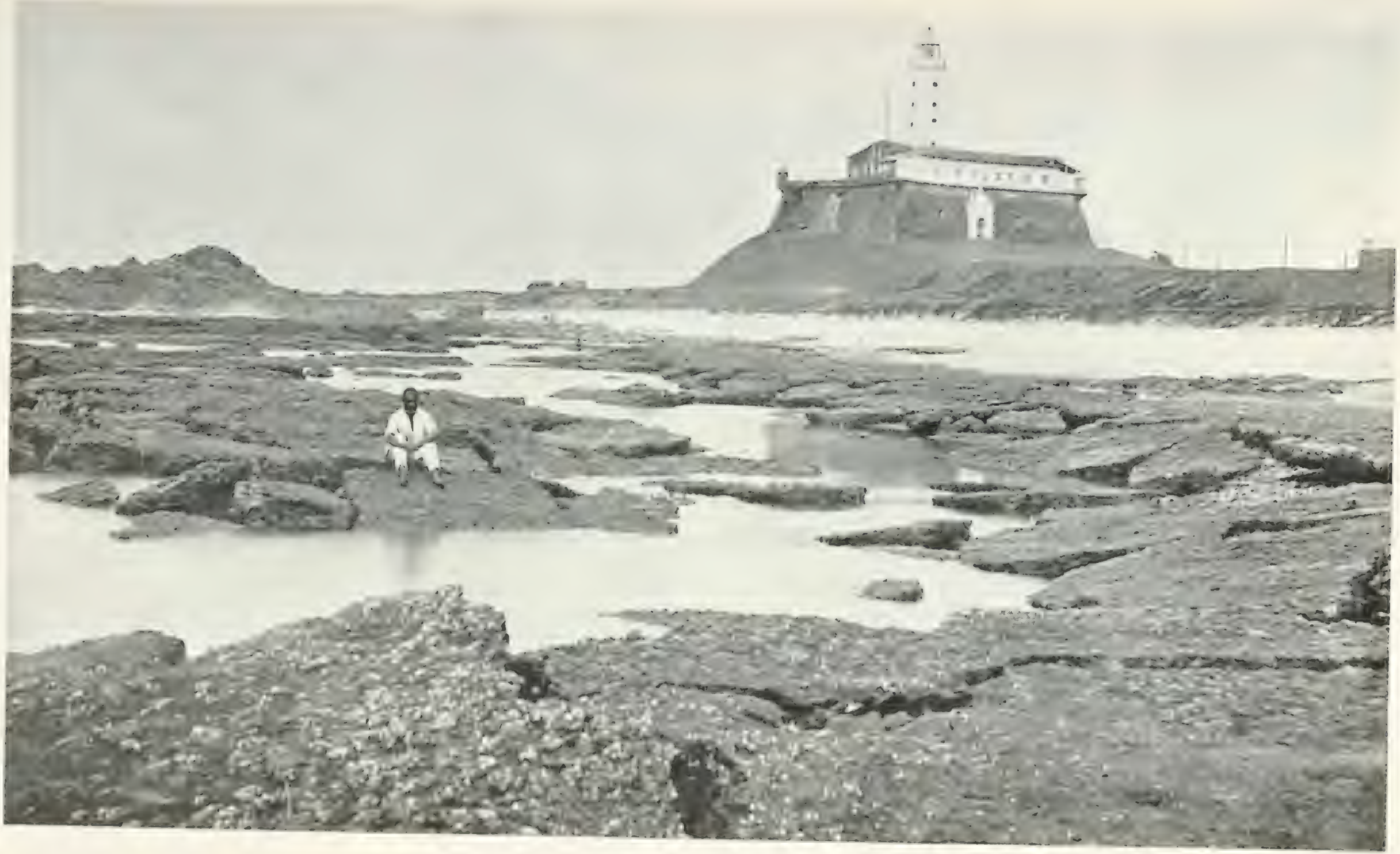
PART OF PANORAMA OF PL. 52A.



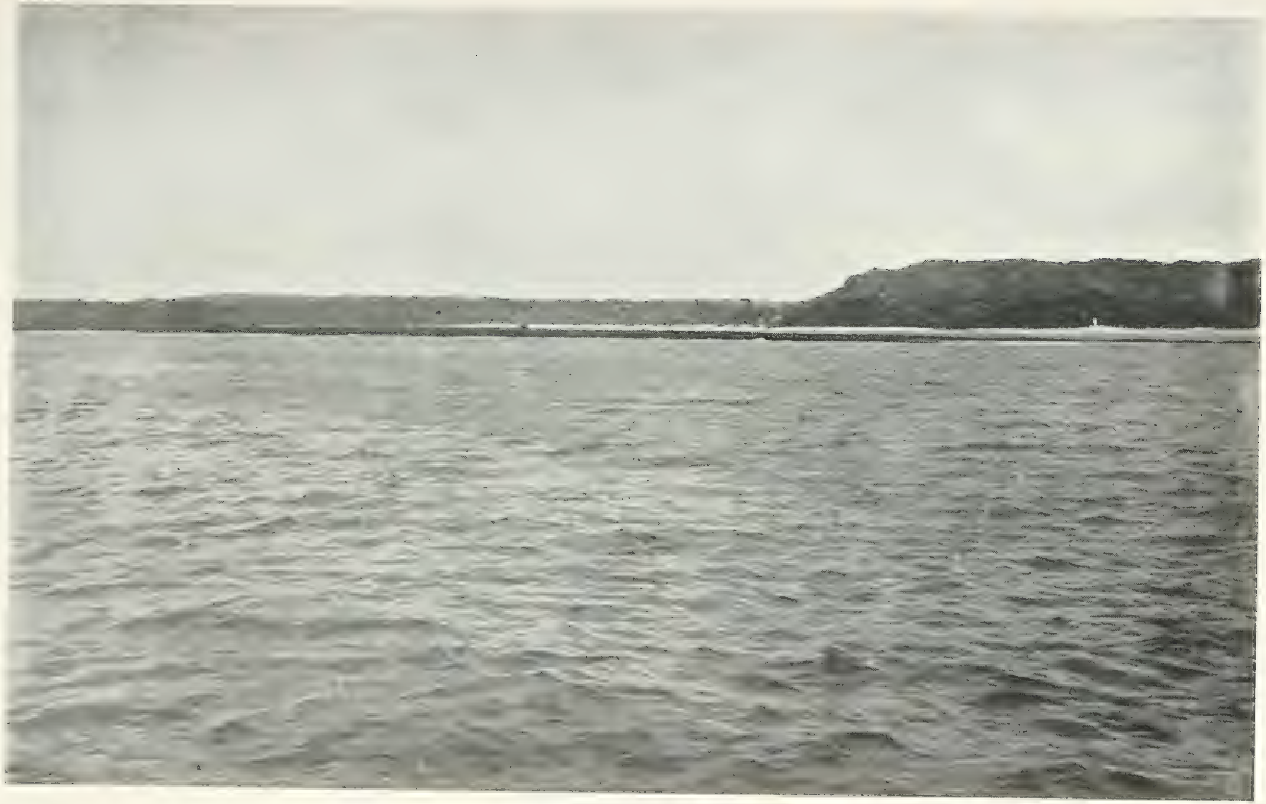
CABO SANTO AGOSTINHO REEF AT CAMBOA.



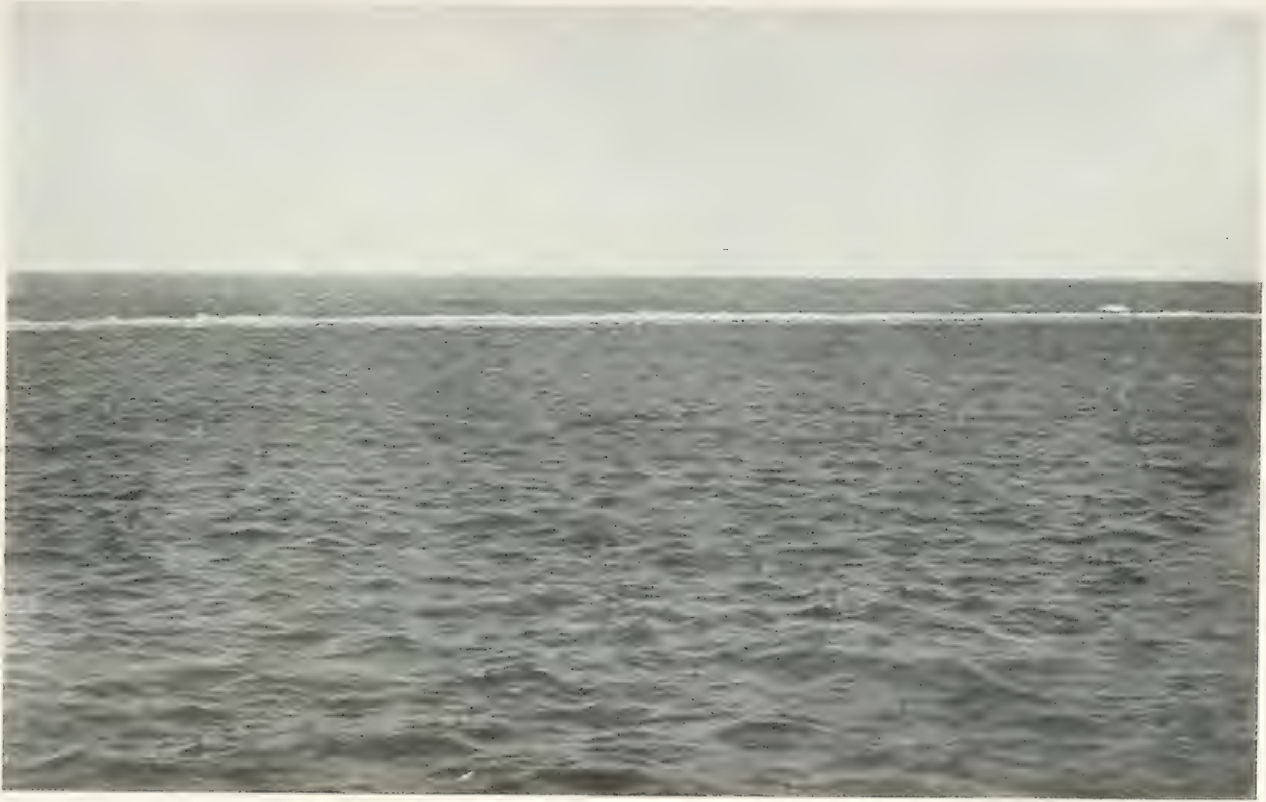
STONE REEF SOUTH OF CABO SANTO AGOSTINHO.



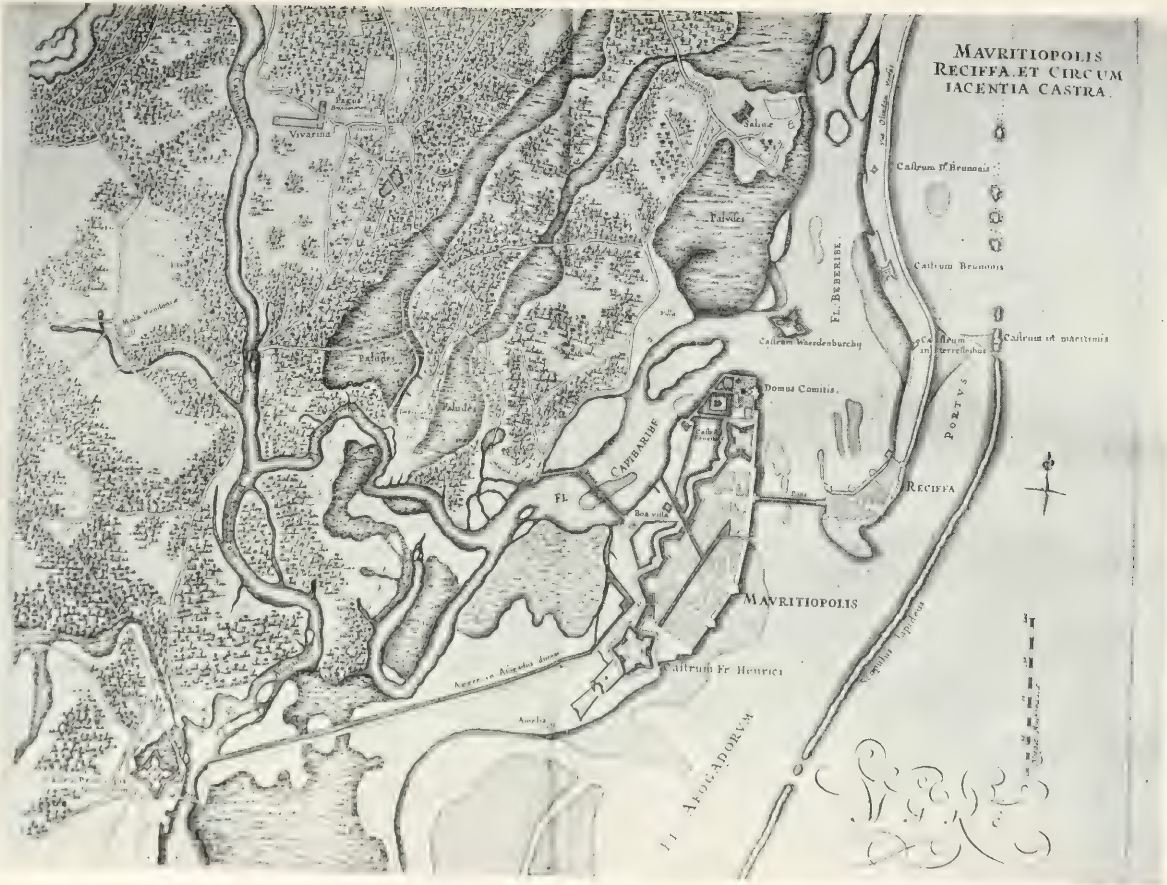
THE SANDSTONE REEF NEAR THE LIGHTHOUSE, BAHIA.



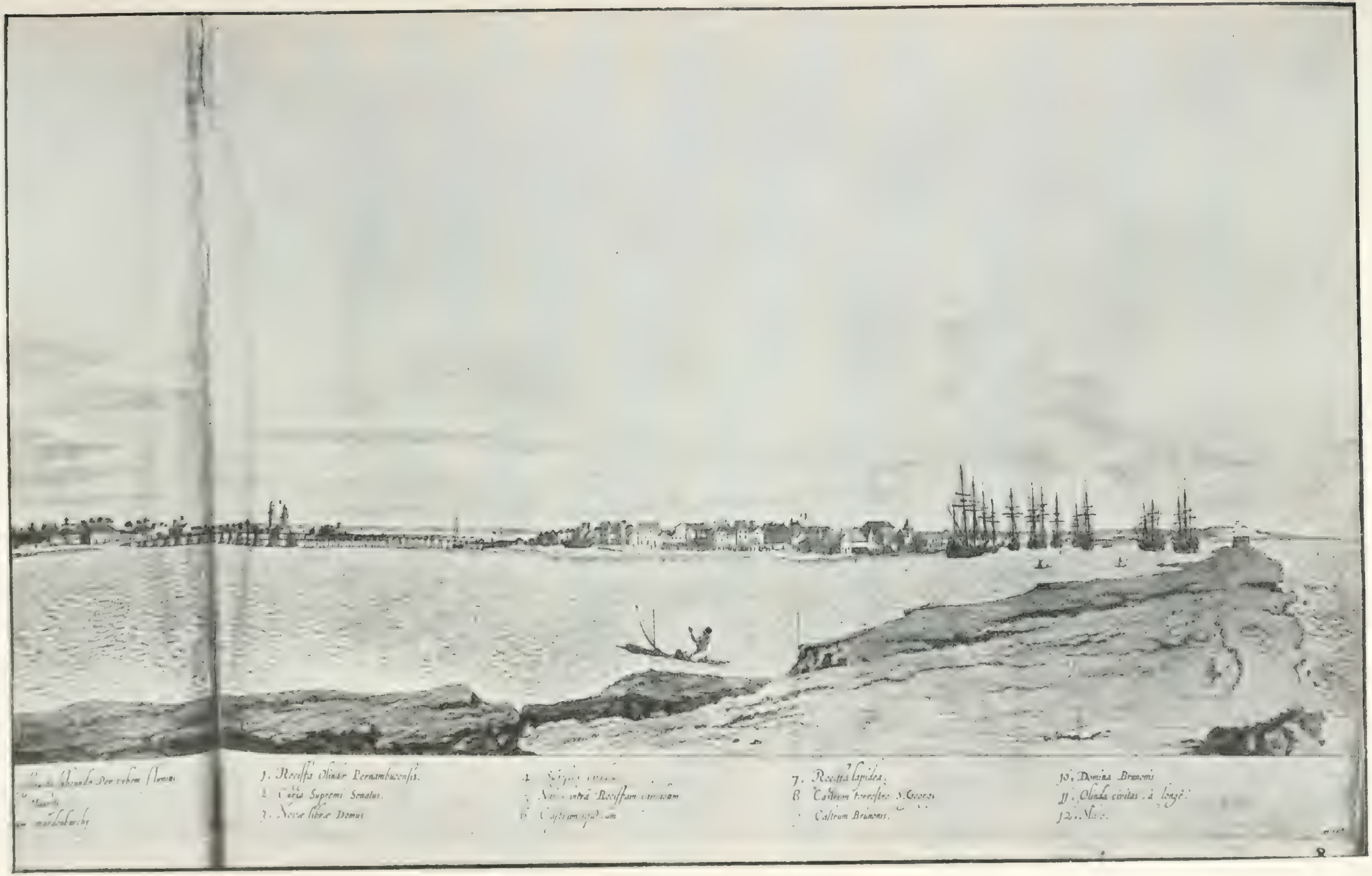
NORTH END OF STONE REEF AT SANTA CRUZ.



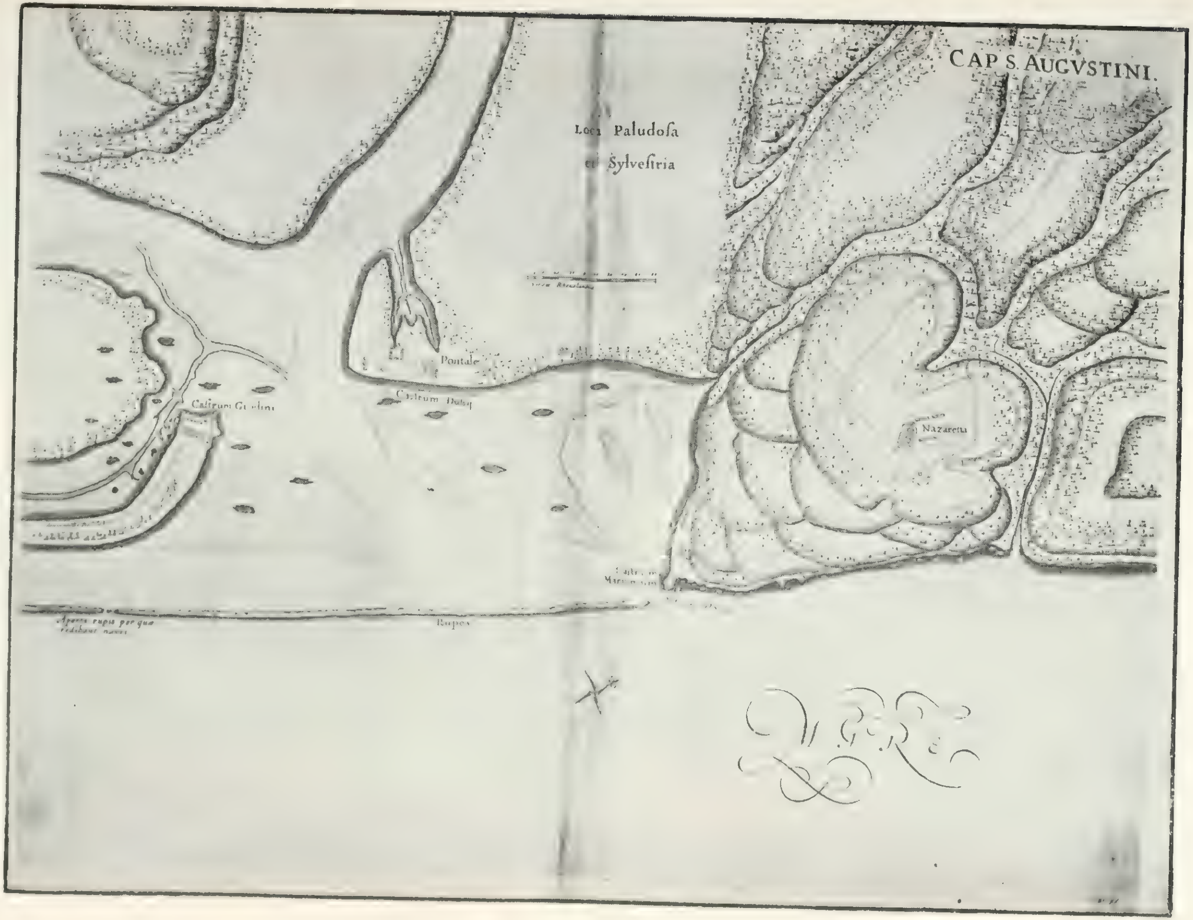
THE STONE REEF AT PORTO SEGURO.


MAVRITIOPOLIS
RECIFFA ET CIRCUM
IACENTIA CASTRA.
Castrum Fr. Brunonis
Castrum Brunonis
Castrum et maritimis
Castrum in terrestribus
FL. BEBERIBE
Castrum Waerdenburchy
Domus Comitis.
PORTVS
RECIFFA
MAVRITIOPOLIS
Castrum Fr. Henrici
CAPIBARIBE
FL
Boa villa
Salinae
Paludes
Paludes
Paludes
Vivarina
Pagus
Agger in Afogados ducens
Amelia
AFOGADORVM
Scopulus lapideus

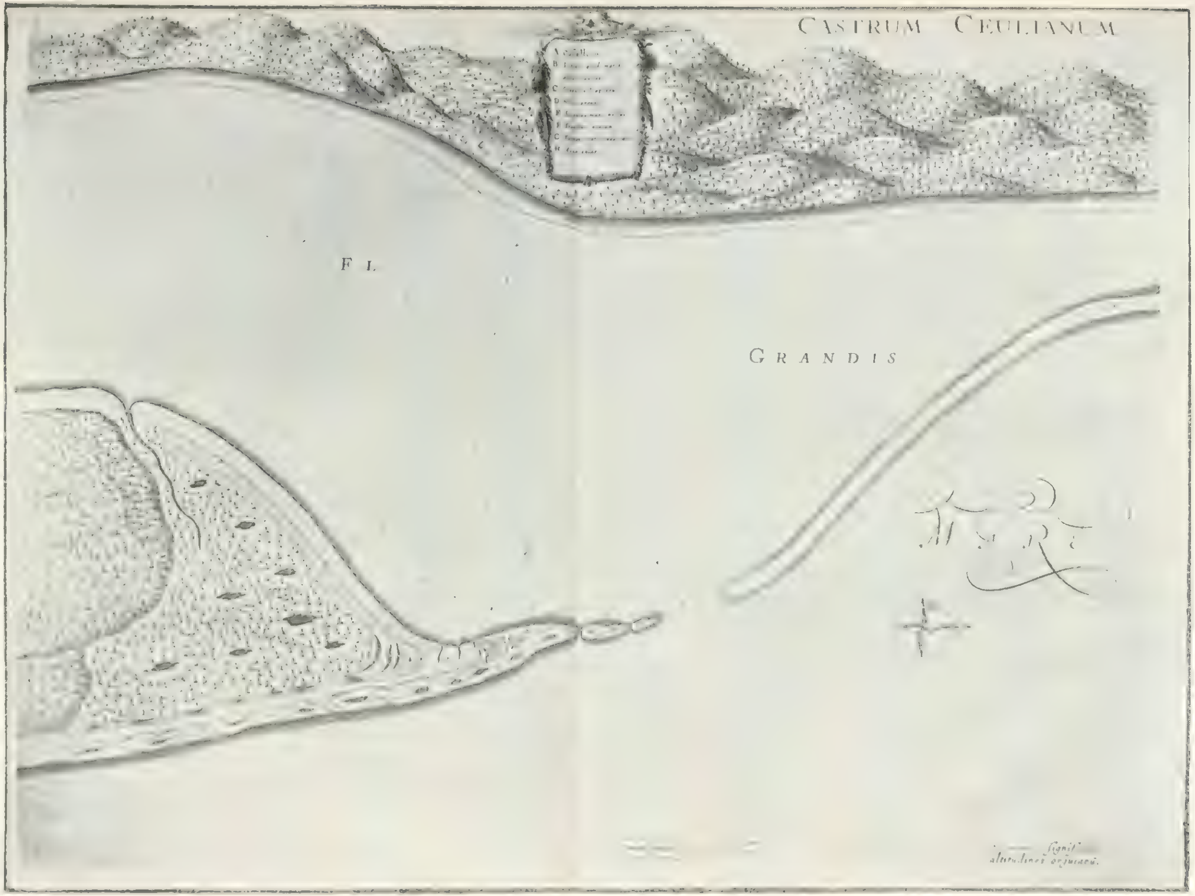
COPY OF THE MAP OF PERNAMBUCO AND THE REEF.


1. Recifſa Olinæ Pernambucenſis.
2. Curia Supremi Senatus.
3. Novæ libræ Domus
5. Naves intrâ Recifſam
7. Recifa lapidea.
8. Caſtrum terreſtre S. Georgi
Caſtrum Brunonis.
10. Domus Brunonis
11. Olinda civitas, à longè.
12. Mare.

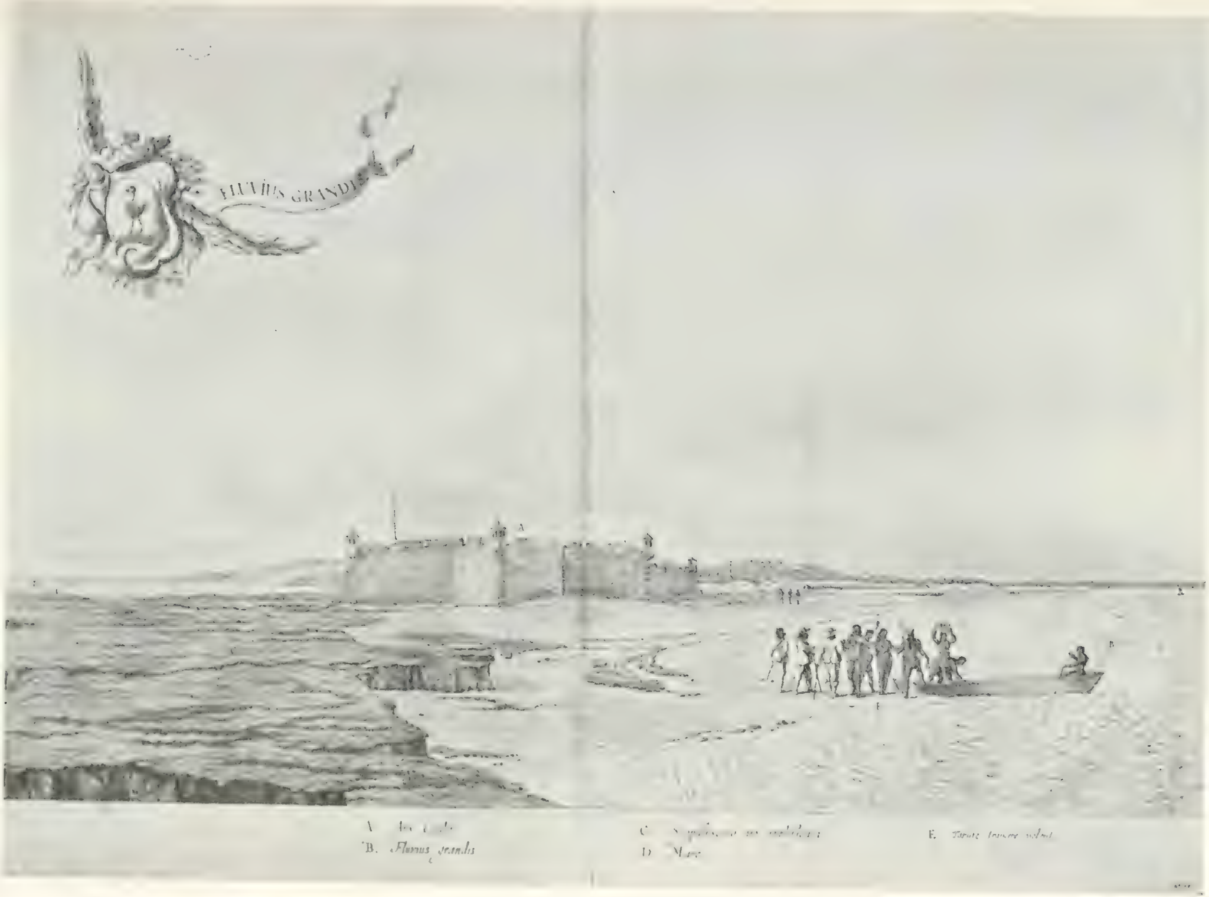
VIEW OF THE STONE REEF NEAR PERNAMBUCO.


CAP S. AUGUSTINI.
Loca Paludoſa
et Sylveſtria
Pontale
Nazareth
Rupes
Aperta rupis per qua
redibant naves

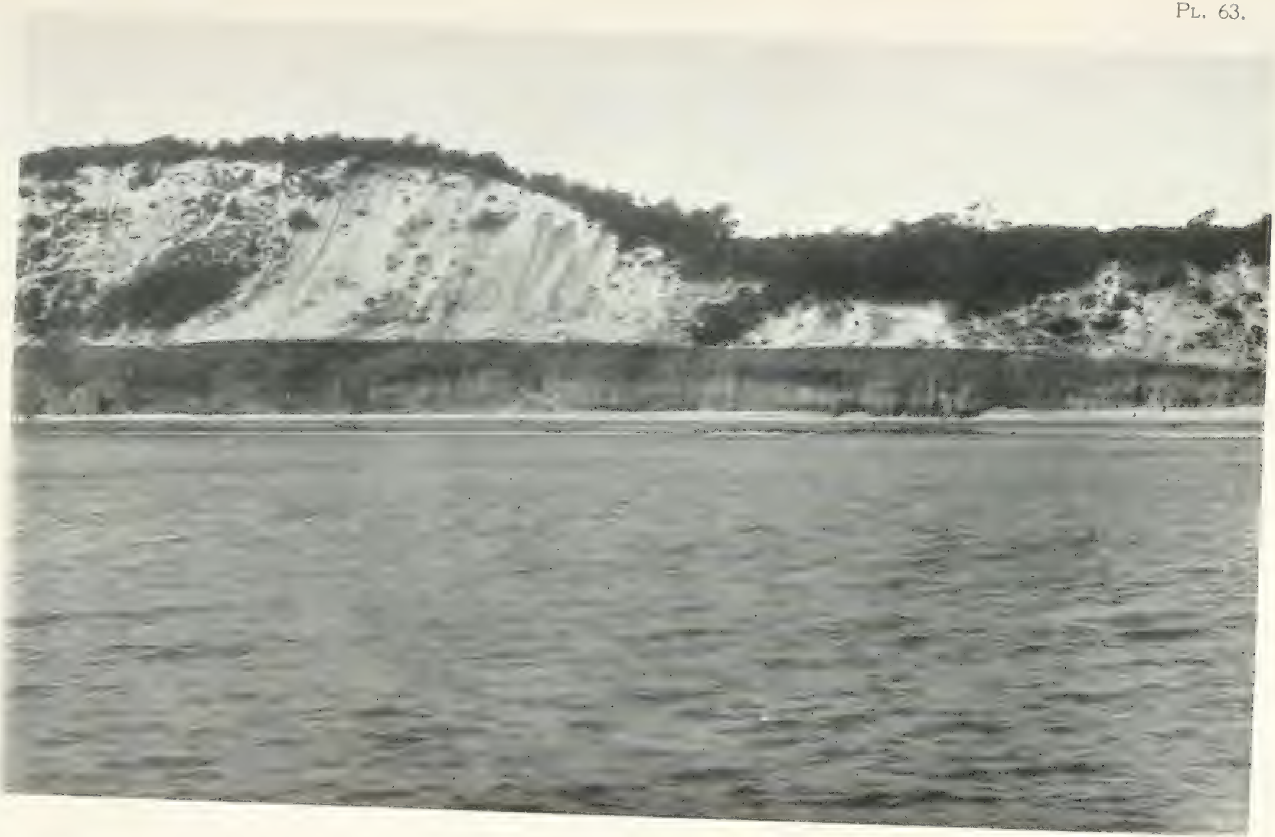
THE STONE REEF AT CABO SANTO AGOSTINHO.


CASTRUM CEULIANUM
F L
GRANDIS

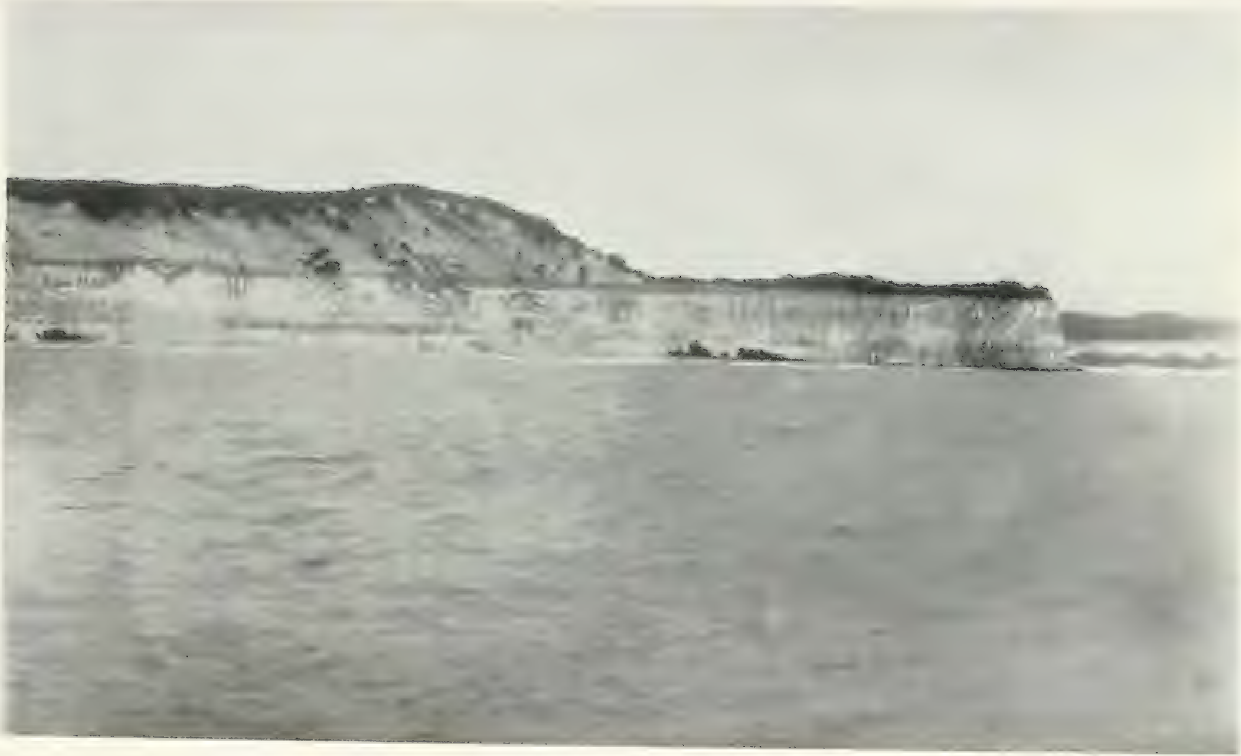
MAP OF THE STONE REEF AT NATAL.


FLUVIUS GRANDIS
A
B. Fluvius grandis
C
D. Mare
E

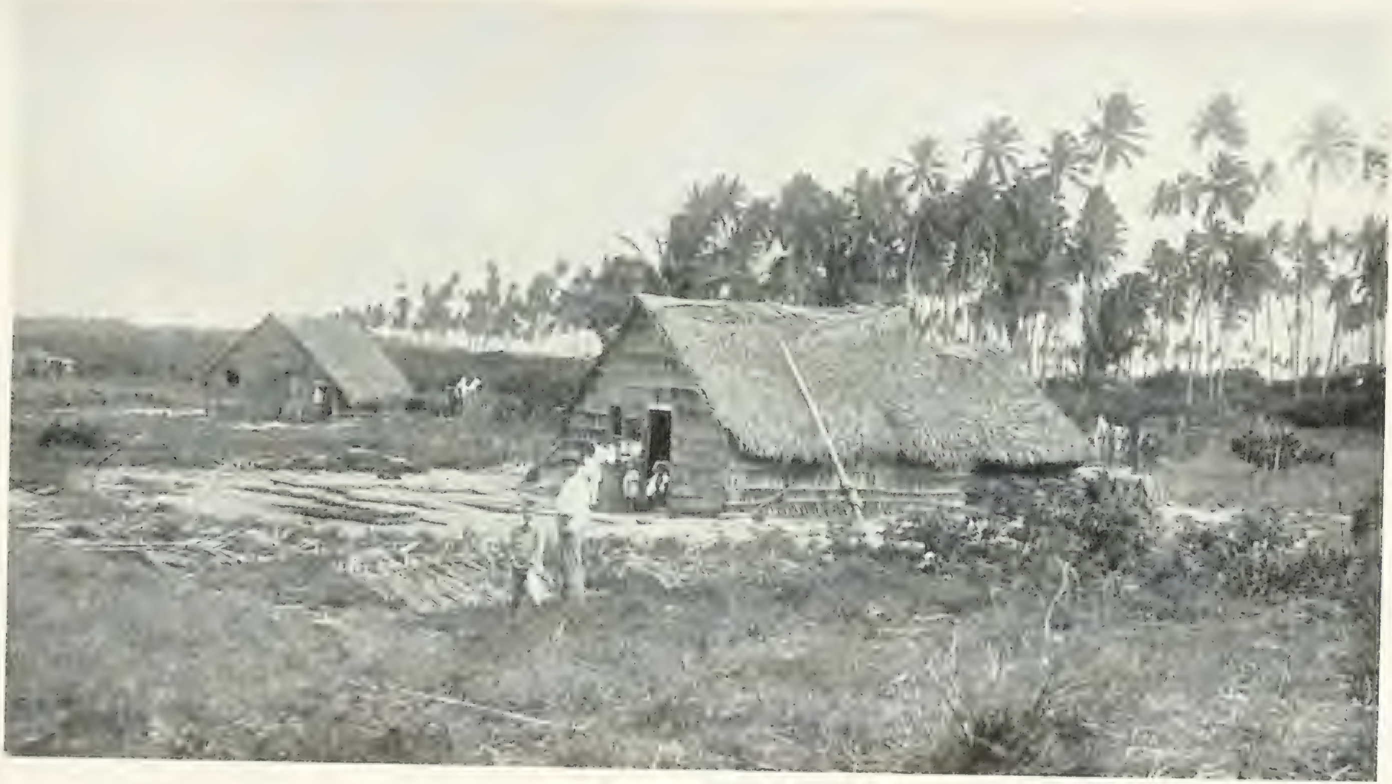
FORTALEZA DOS REIS MAGOS.



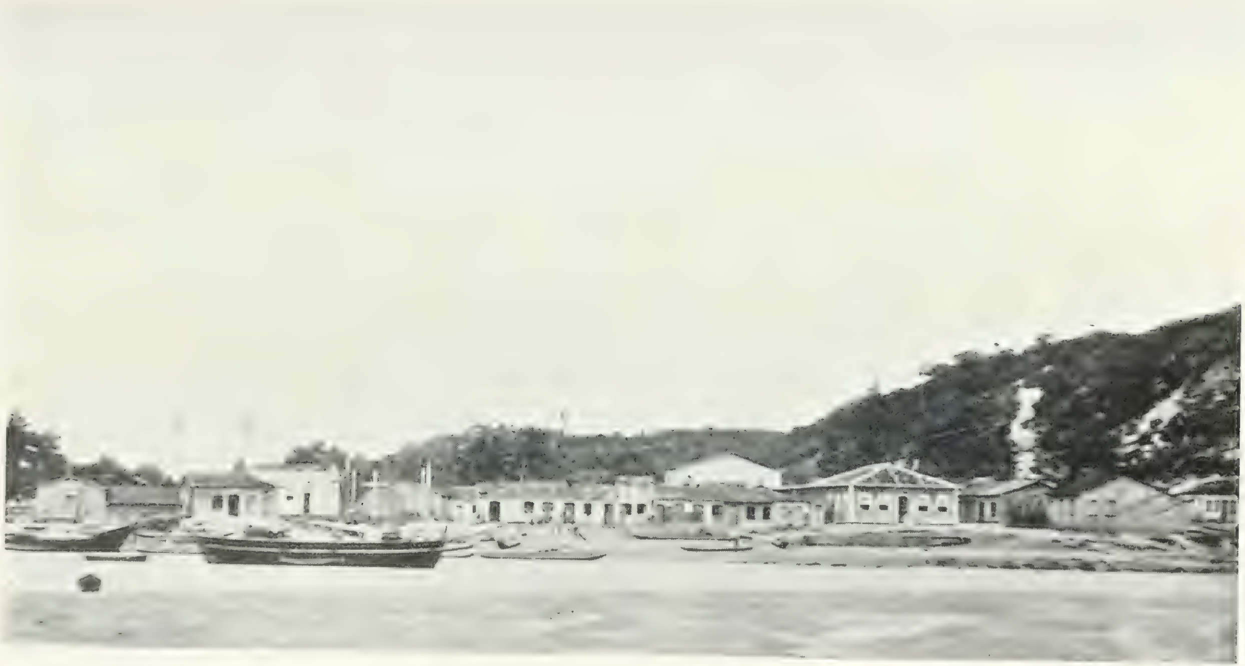
TERTIARY (?) CLIFFS AT BAHIA FORMOSA.



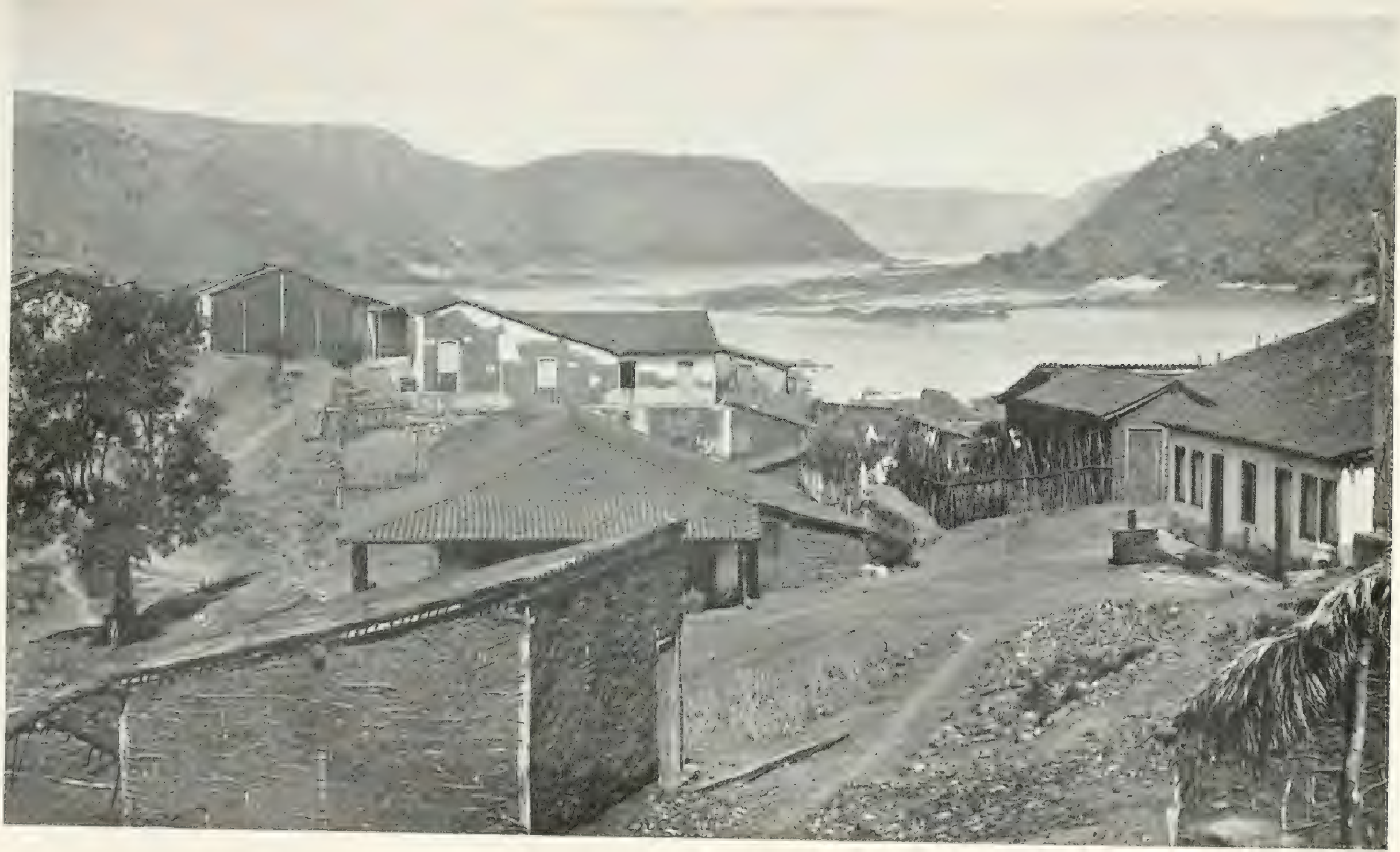
TERTIARY (?) BLUFF AT PIPA.



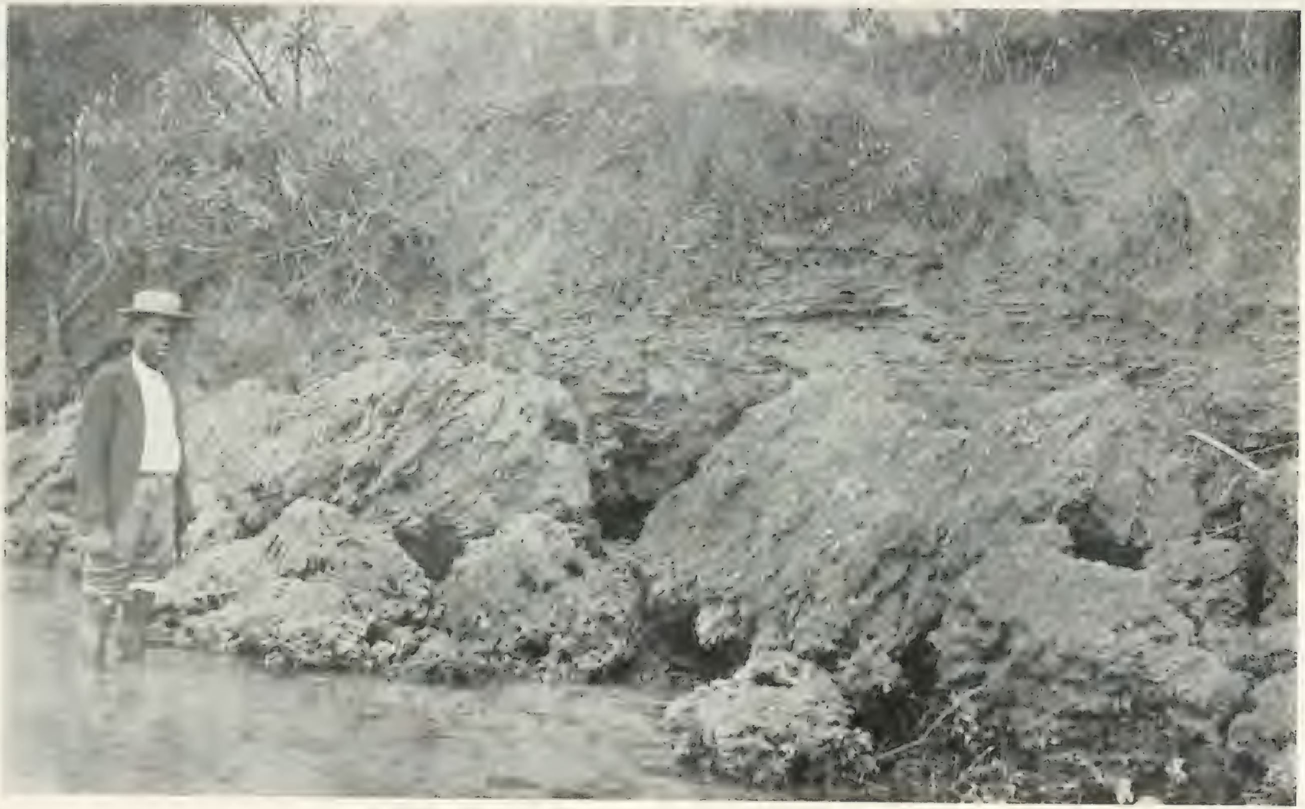
CHARACTERISTIC TOPOGRAPHY, PERNAMBUCO COASTAL SAND PLAIN.



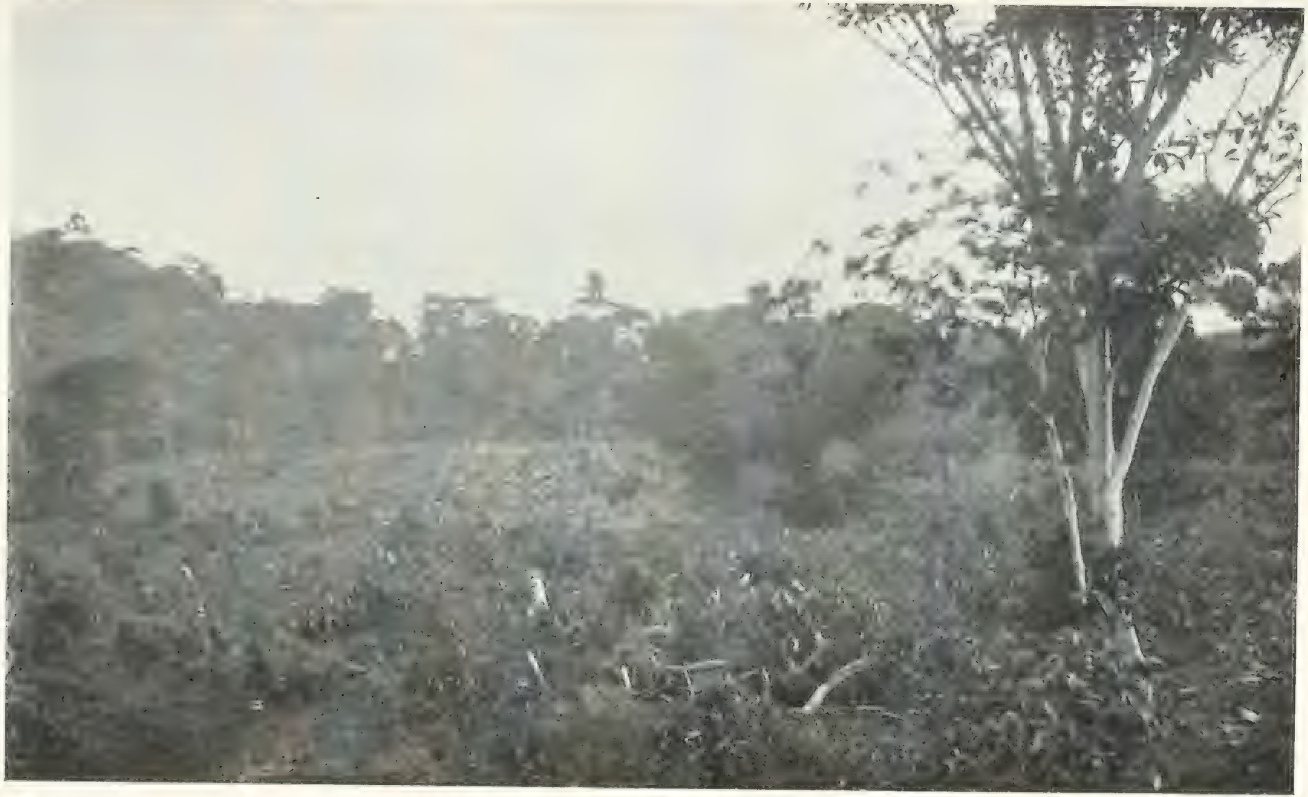
SANTA CRUZ, STATE OF BAHIA, TERTIARY BLUFF.



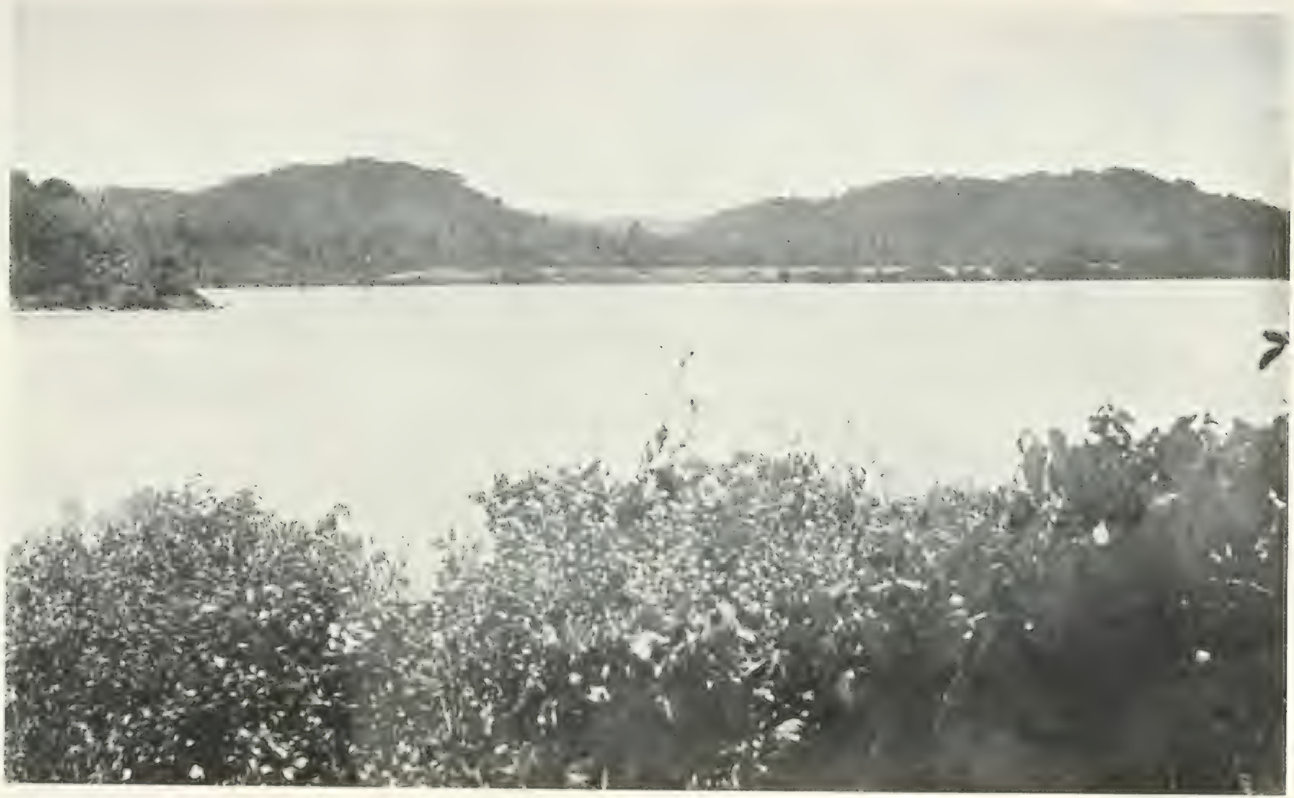
THE GORGE OF RIO SÃO FRANCISCO.



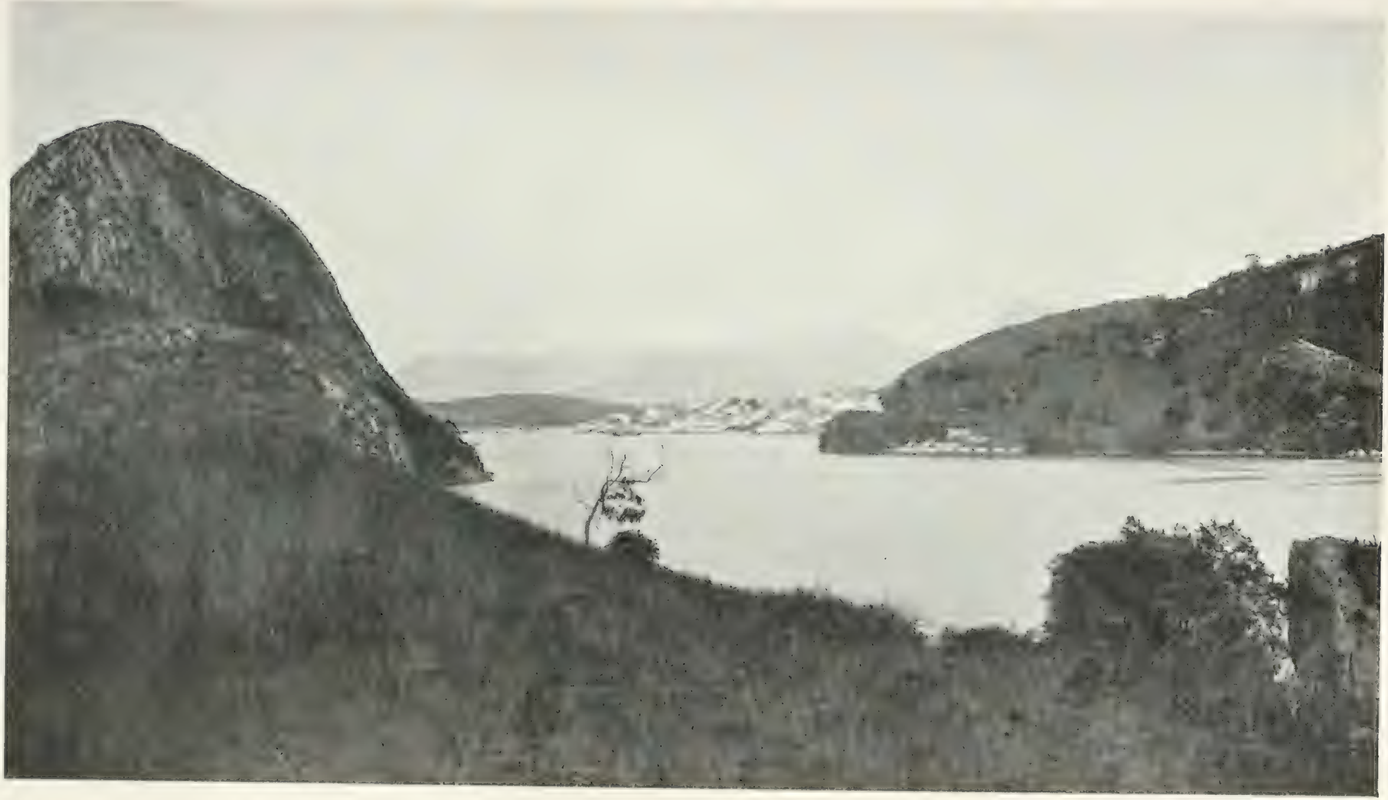
AN ELEVATED BEACH AT PONTA DE AVEIA.



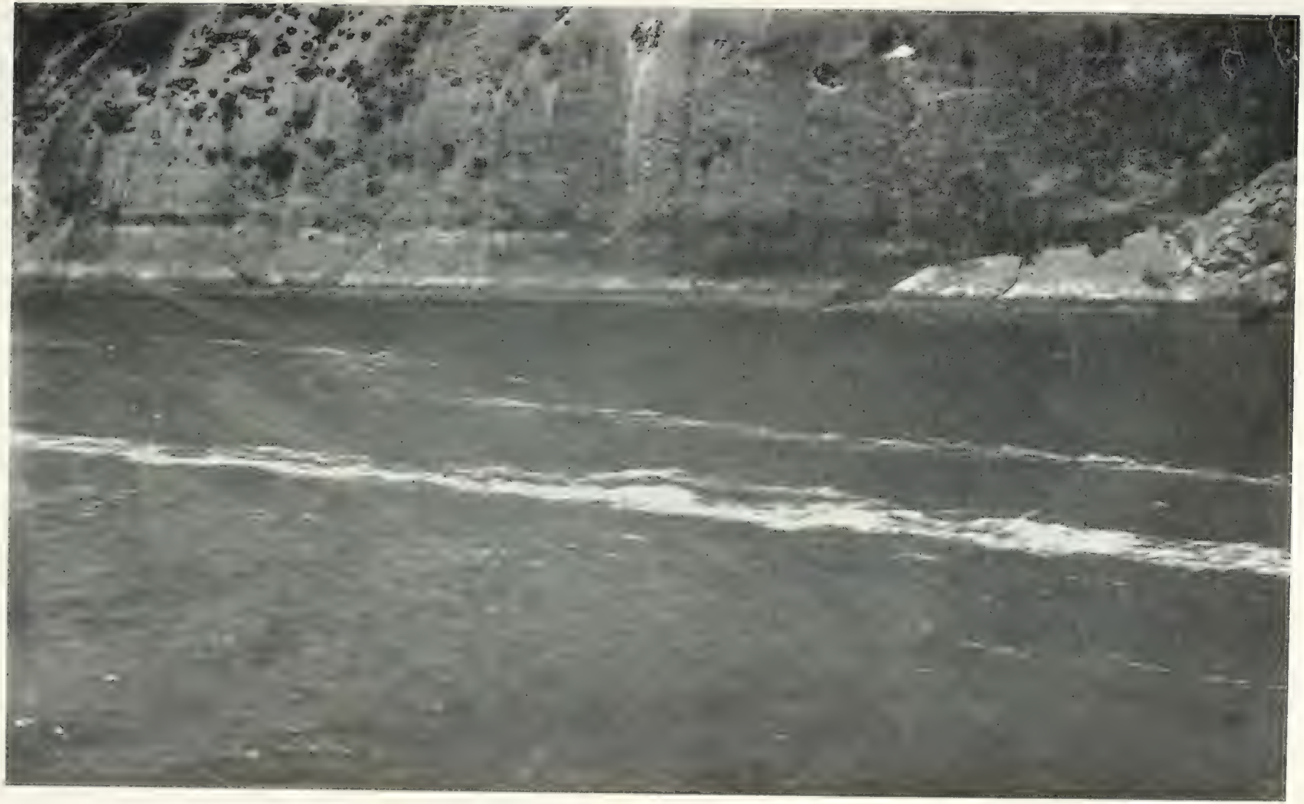
THE TERRACE AT OPABA.



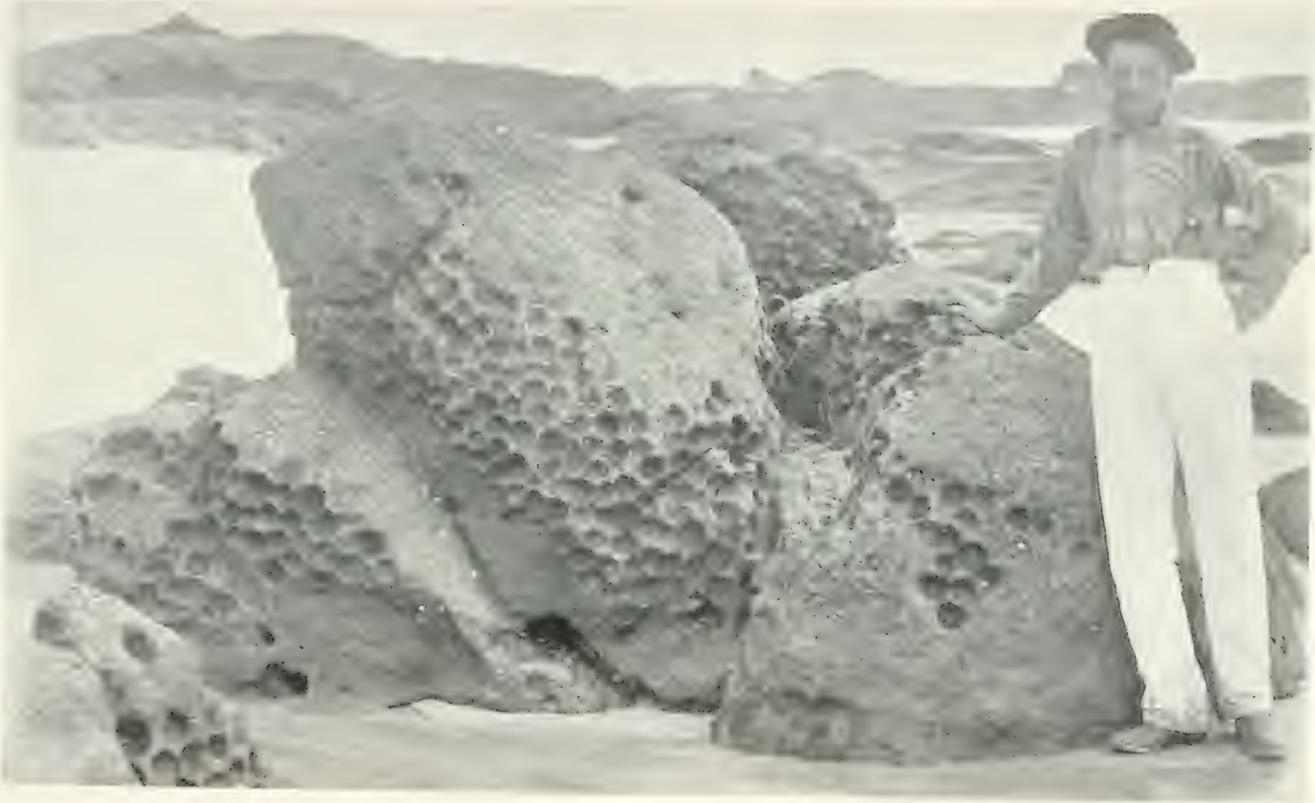
THE TERRACE AT VELLOSA.



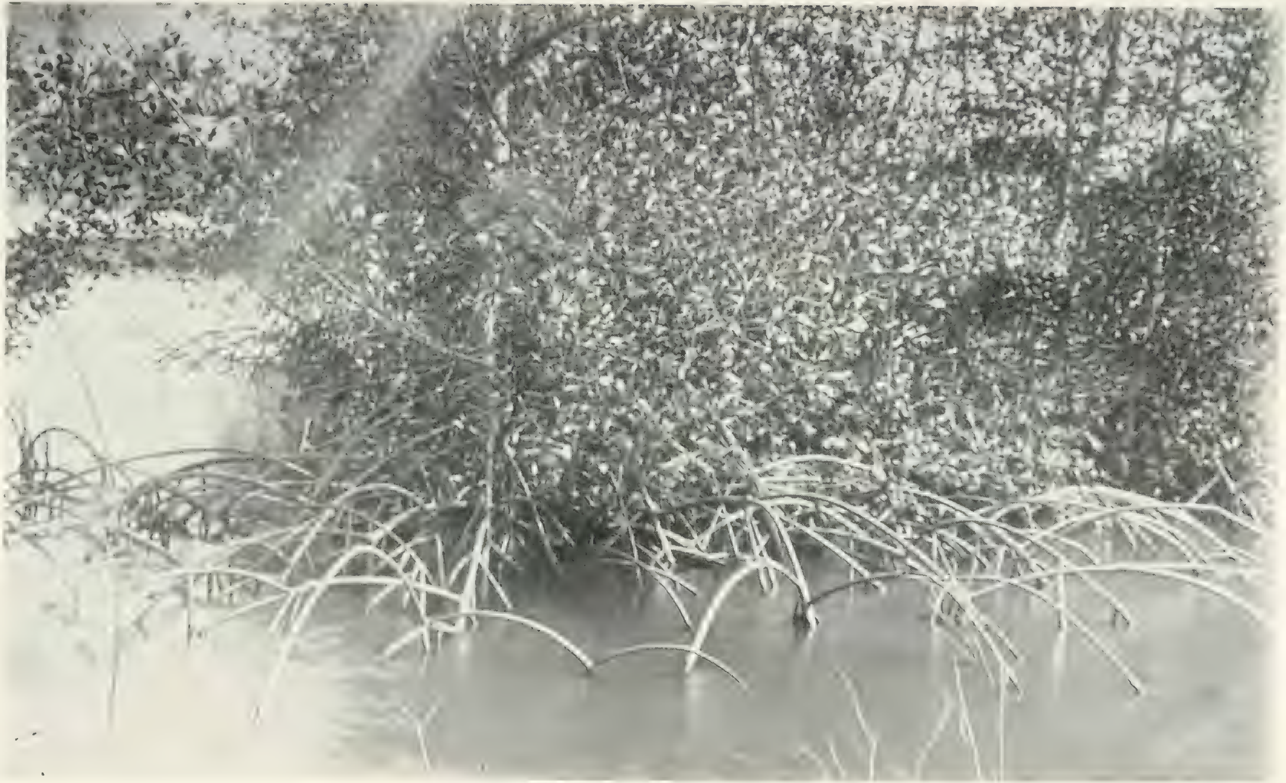
THE PENEDO AT VICTORIA.



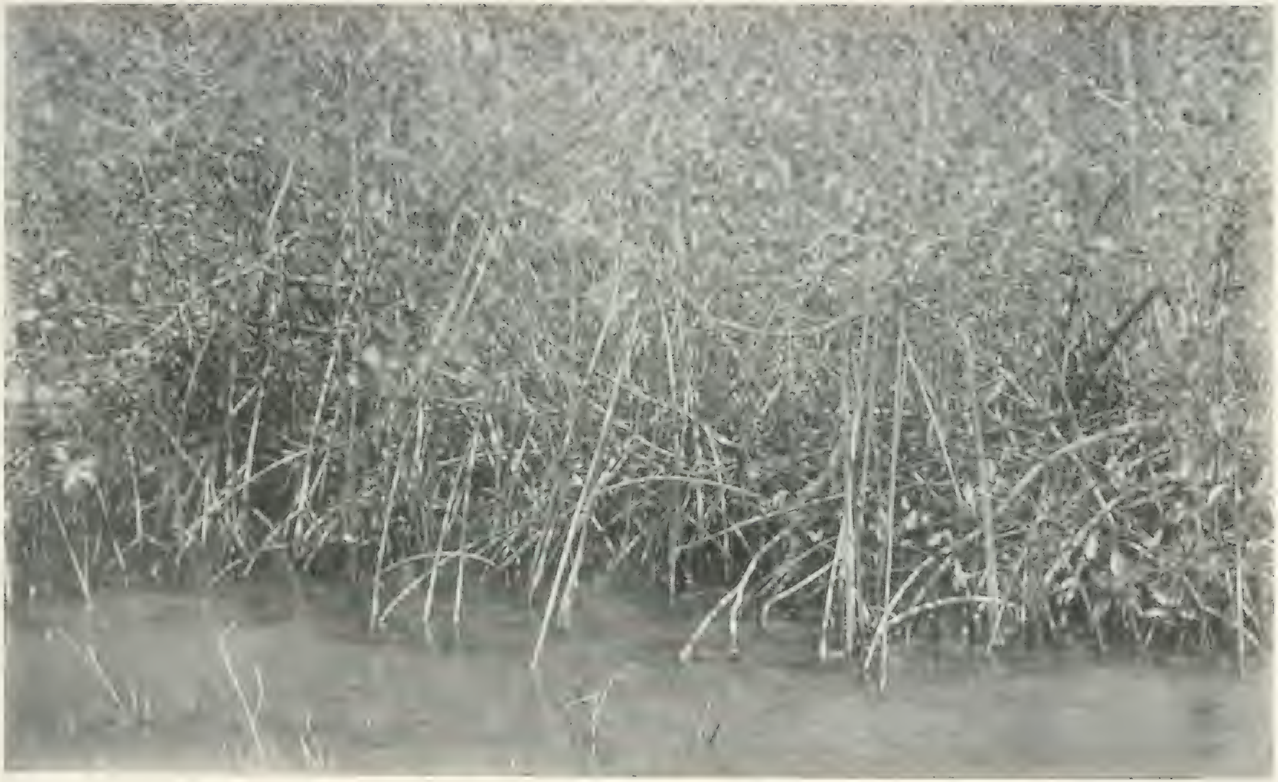
PITS AT VICTORIA ESPIRITO SANTO, SHOWING RECENT ELEVATION.



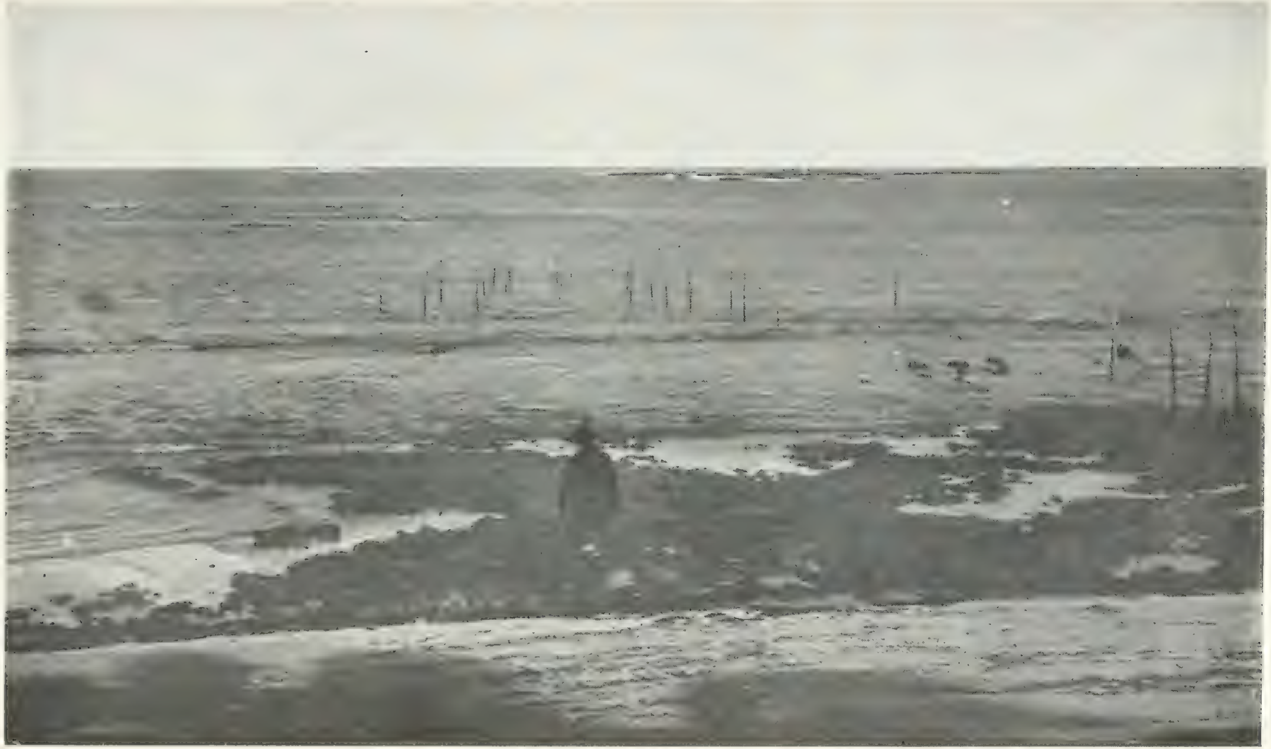
SEA-URCHIN BURROWS IN BLOCKS OF TRACHYTE.



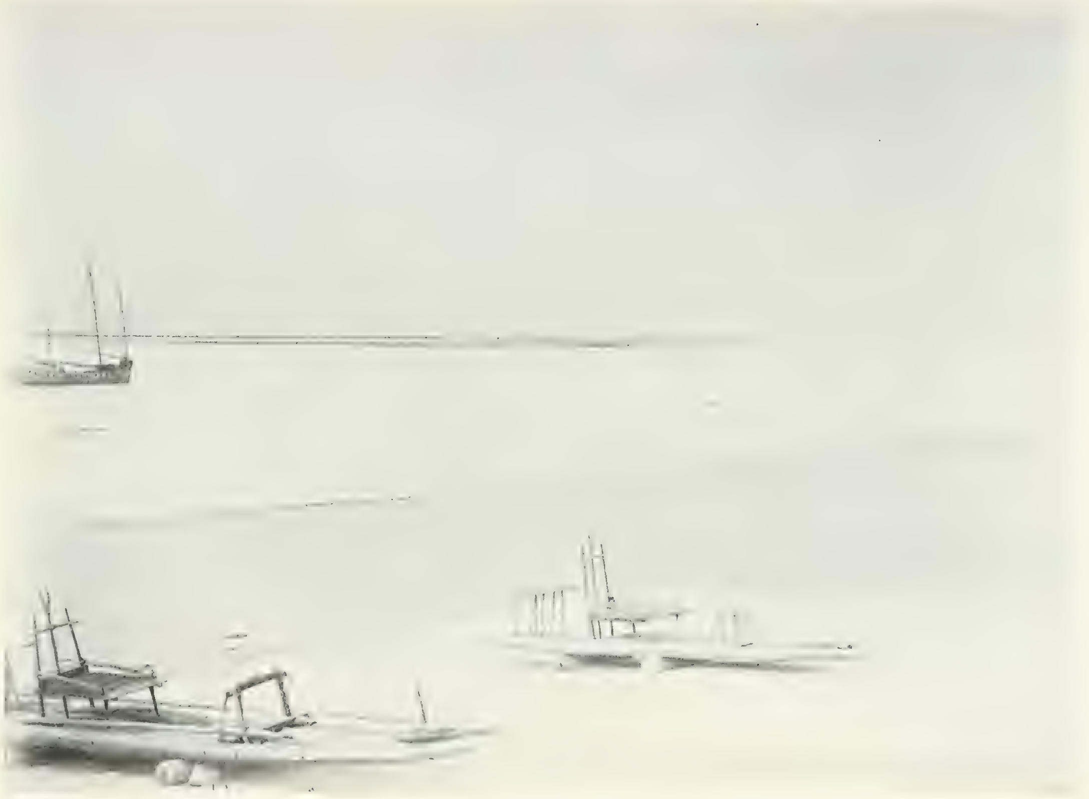
YOUNG MANGROVES.



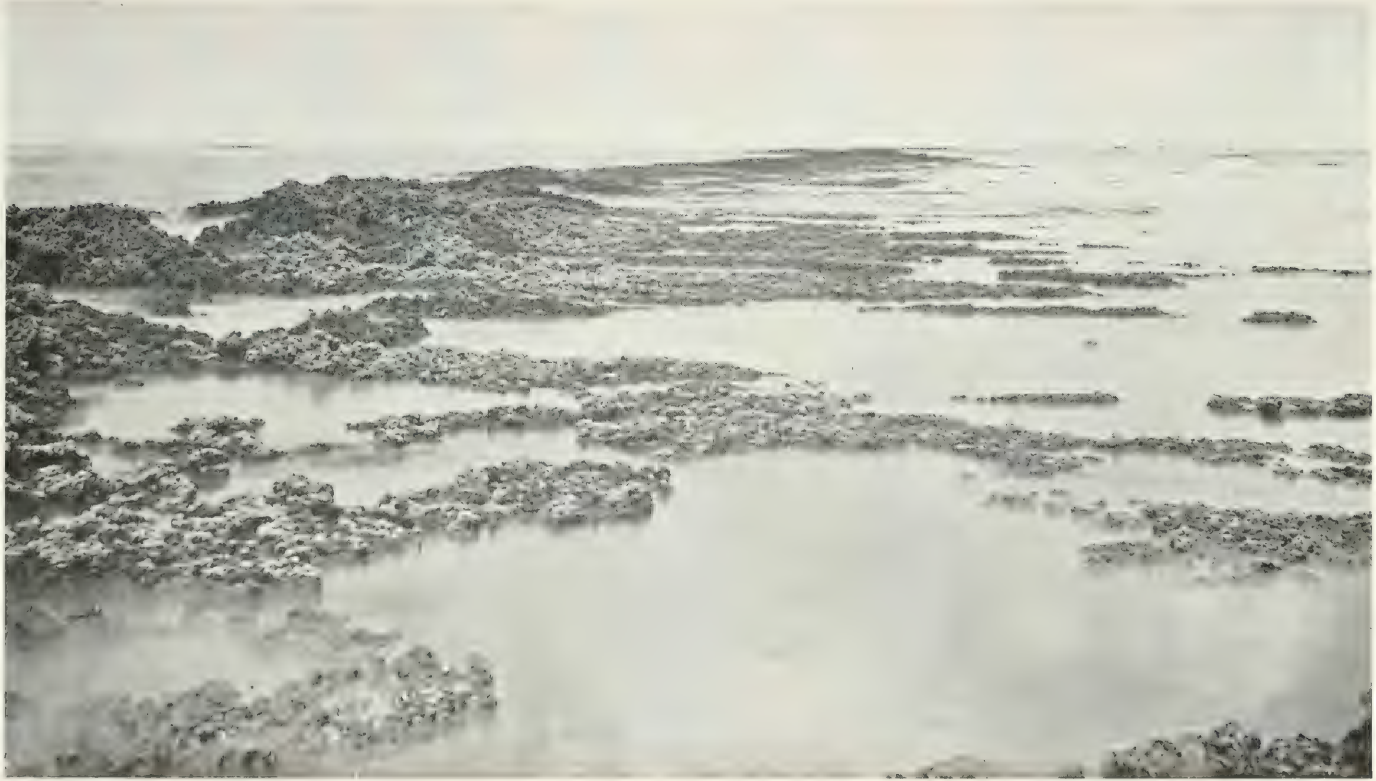
GENERAL VIEW OF THE EDGE OF A MANGROVE SWAMP.



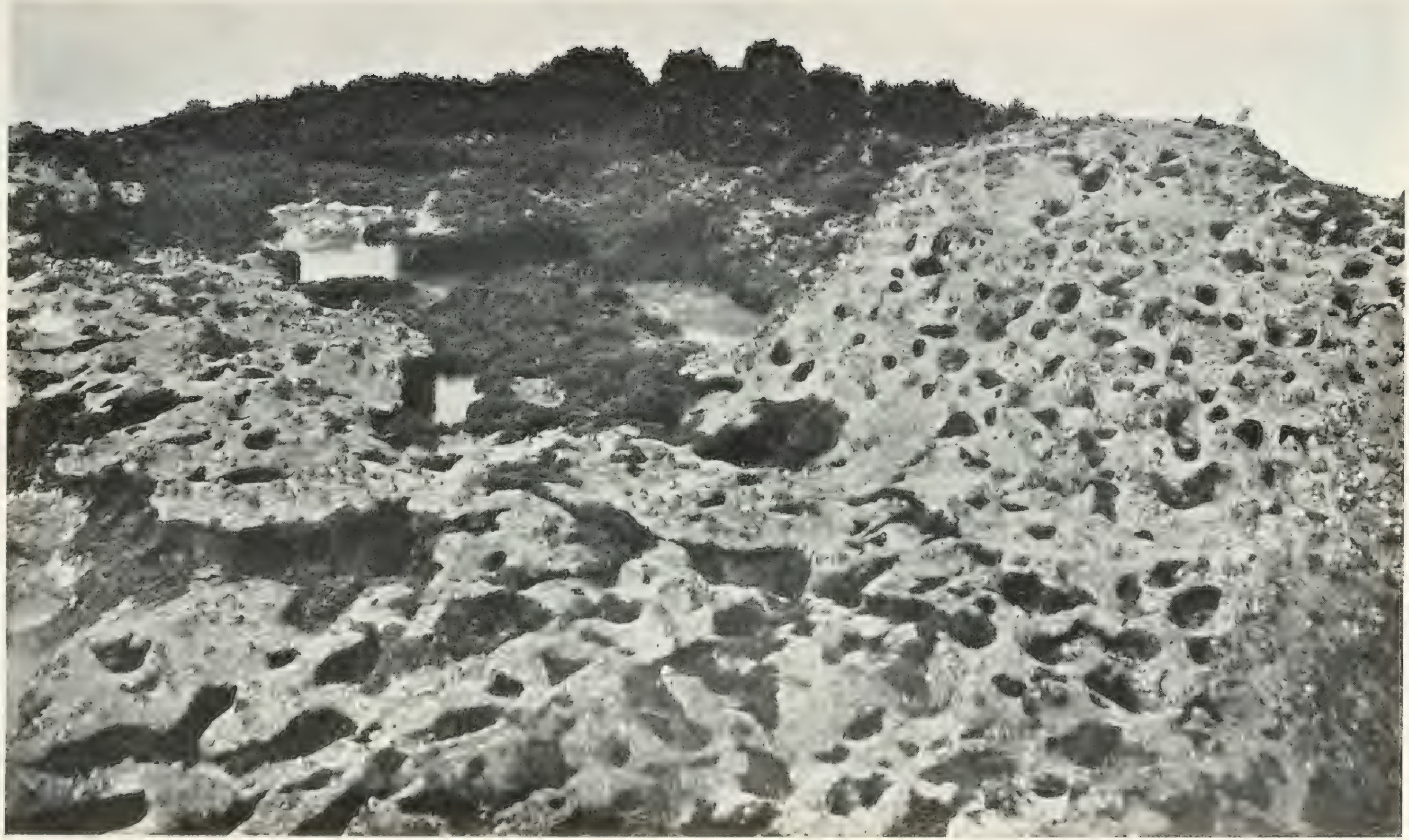
CORAL REEF SOUTH OF SÃO MIGUEL.



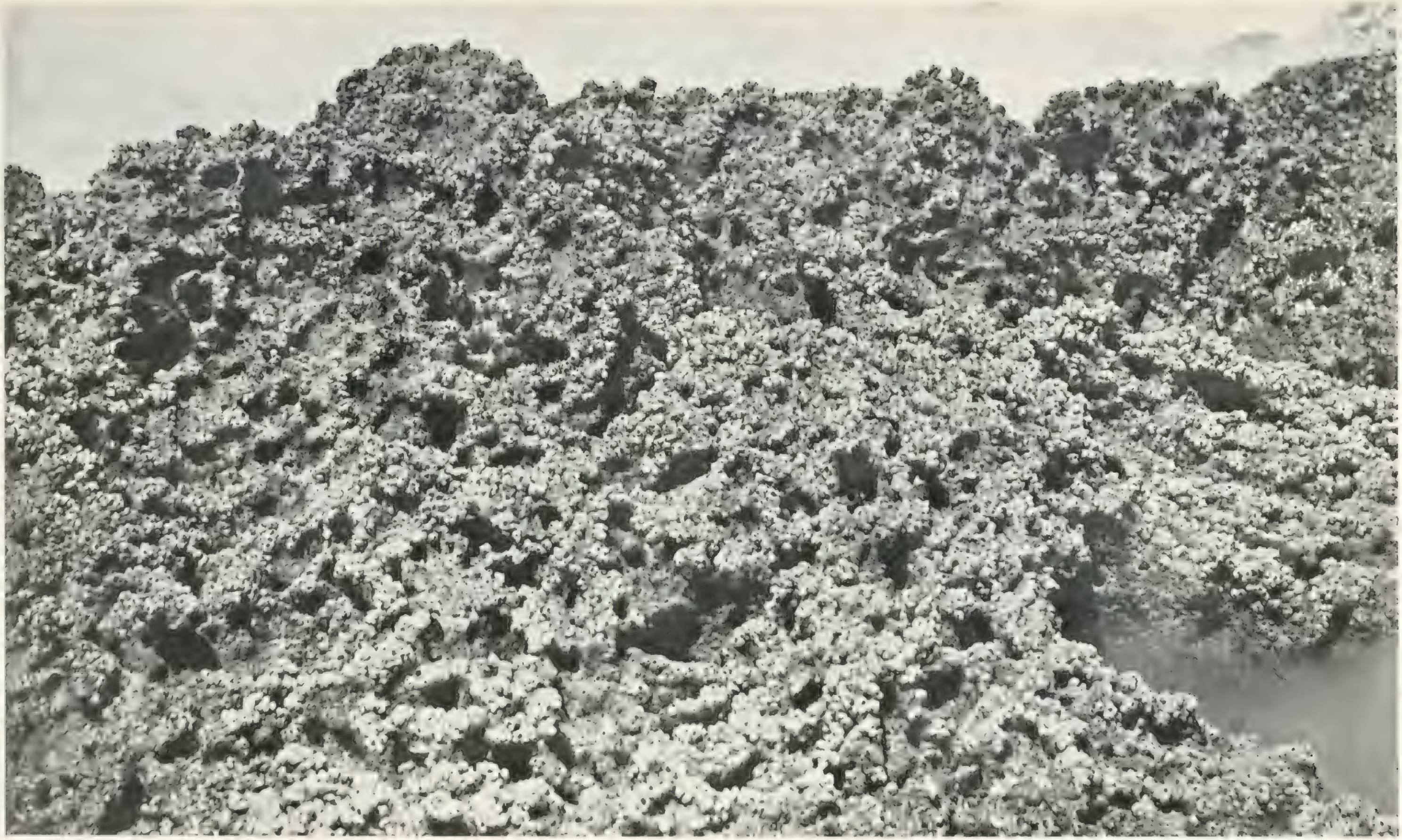
THE MACEIO CORAL REEFS.



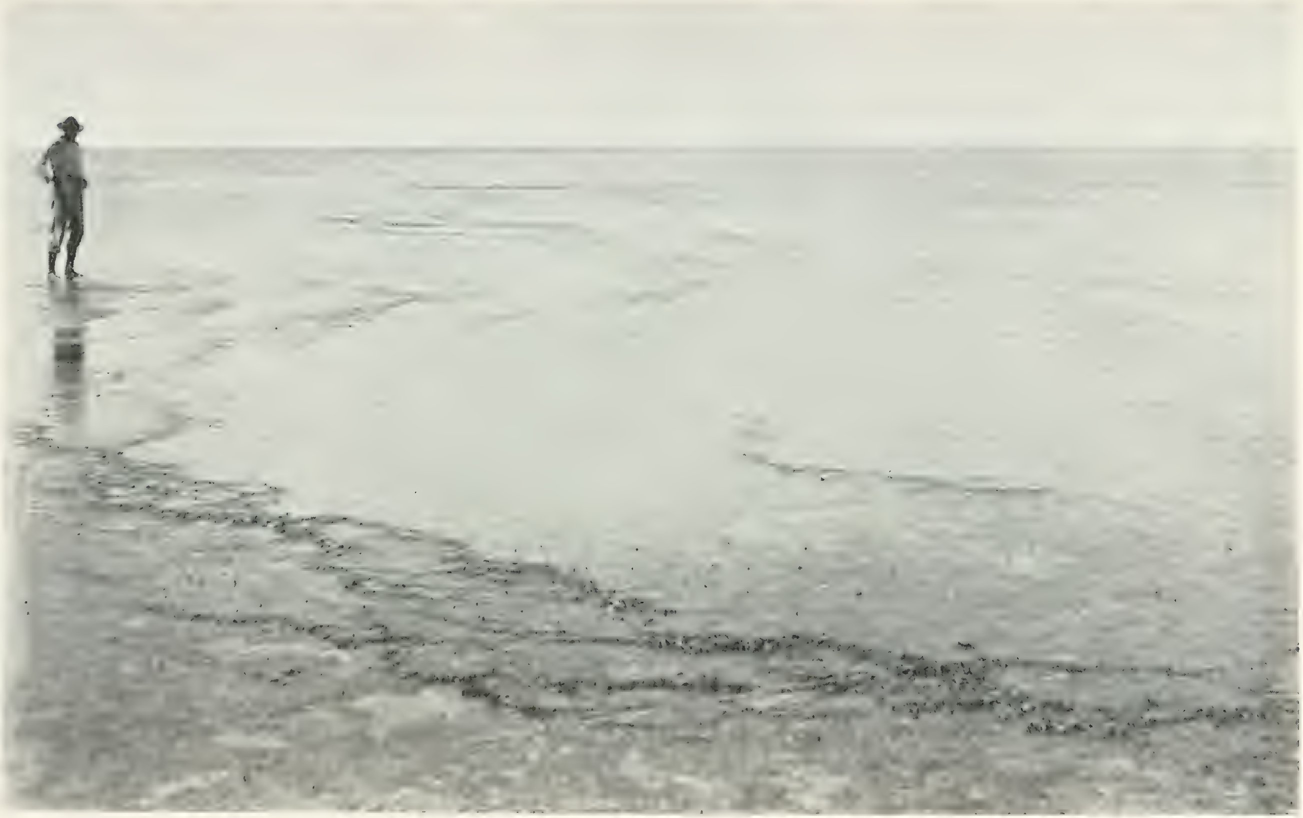
THE ITAPARÍCA CORAL REEF SOUTH OF BAHIA.



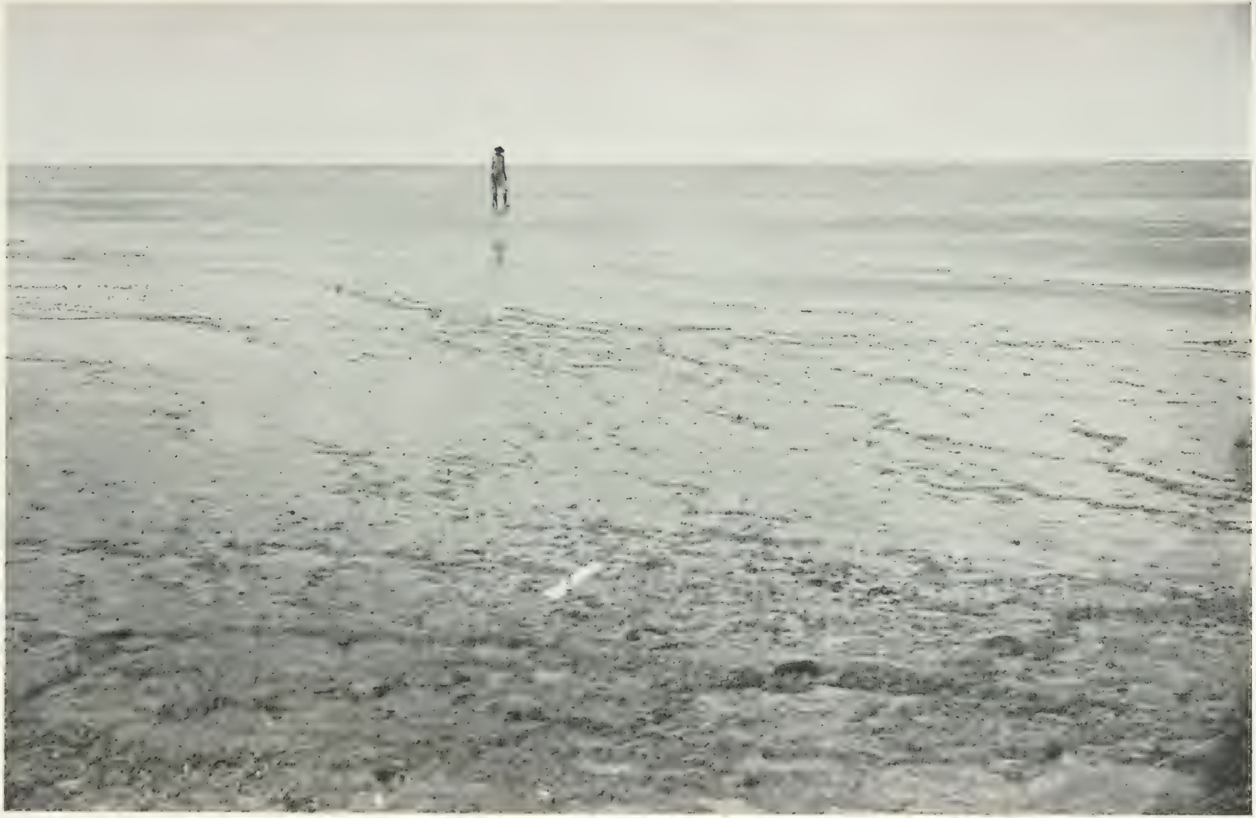
BURROWED DEAD CORAL REEF. ITAPARÍCA.



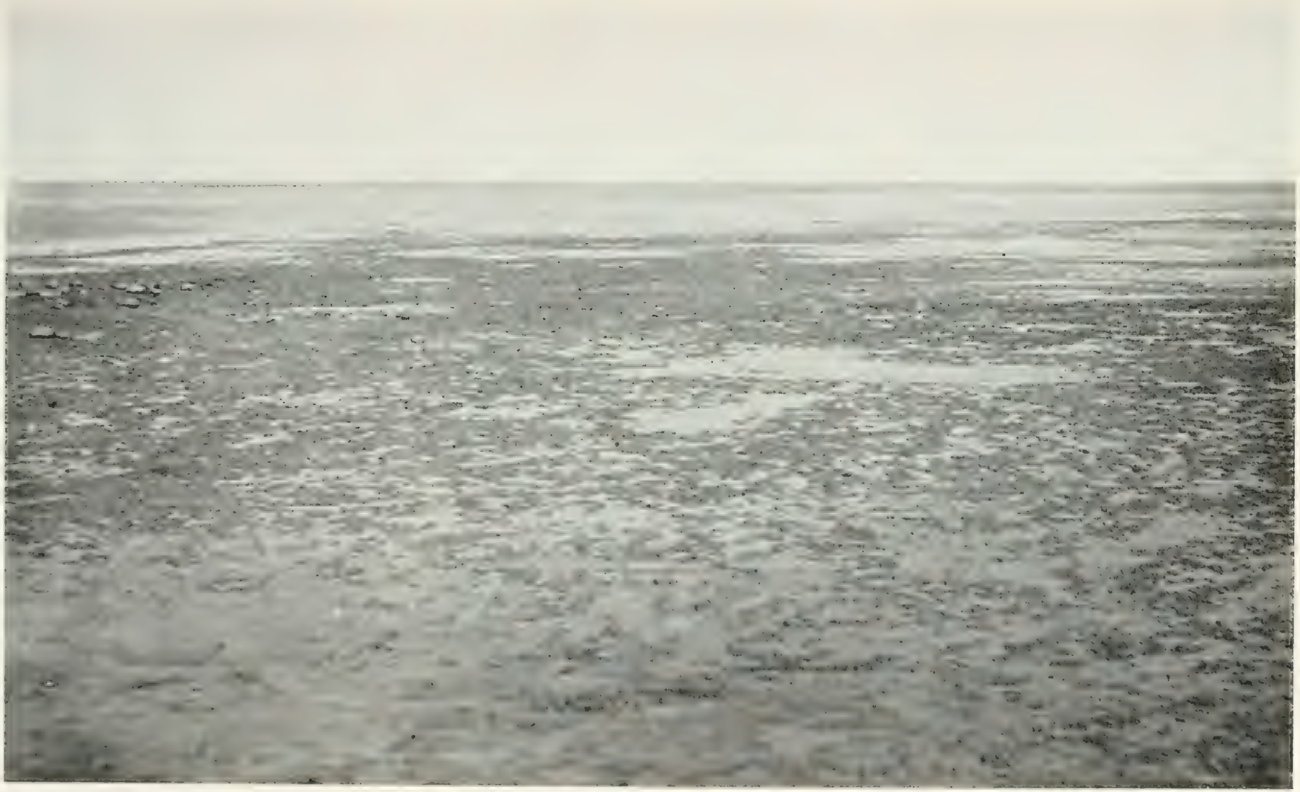
BARNACLES ON THE SURFACE OF A DEAD CORAL REEF.



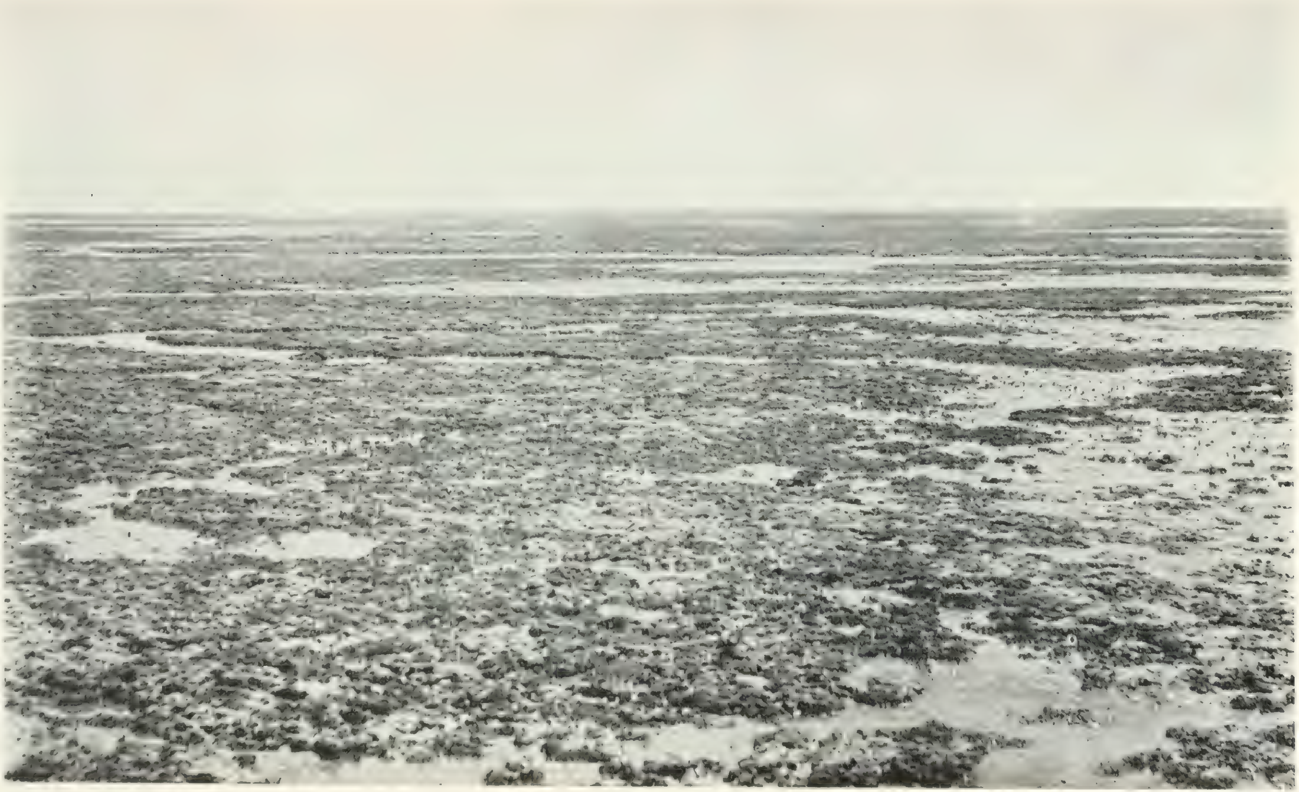
THE LIXA CORAL REEF OFF THE CARAVELLAS COAST.



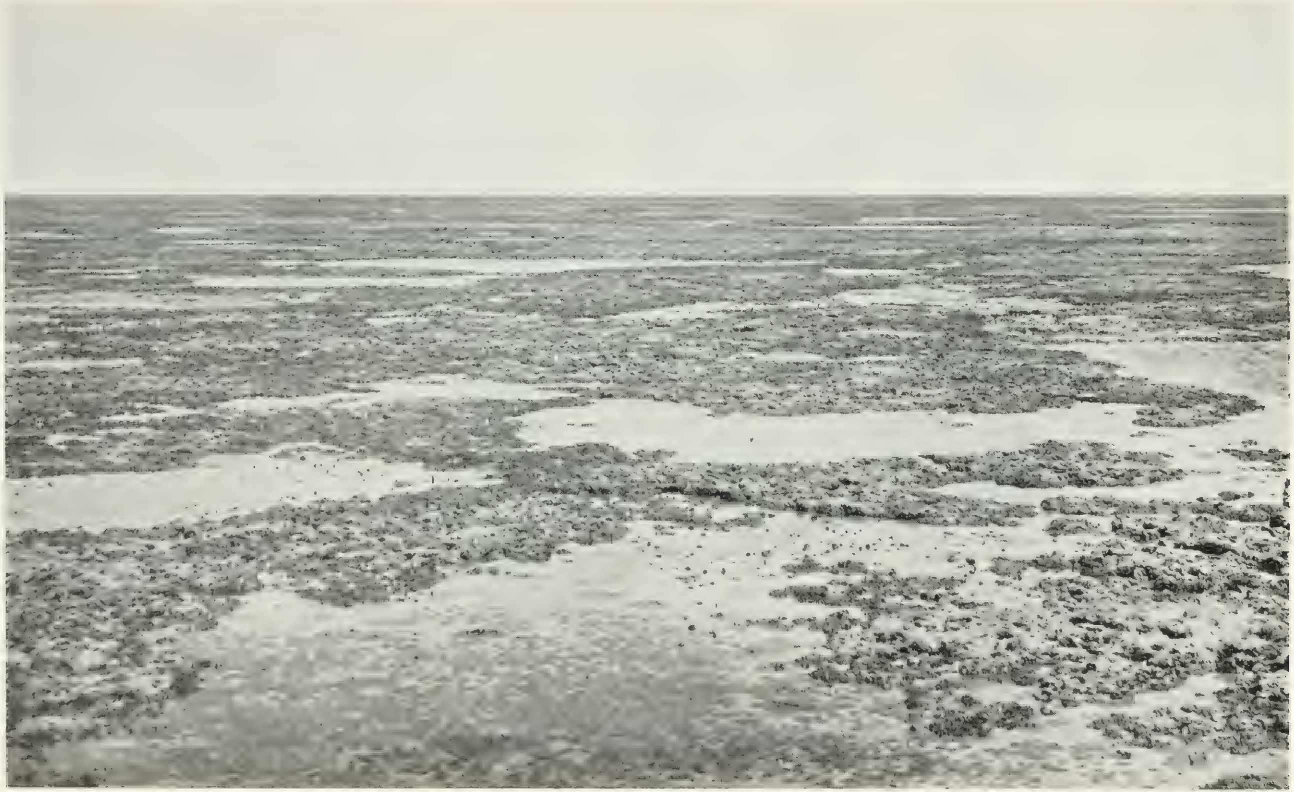
LIXA CORAL REEF.



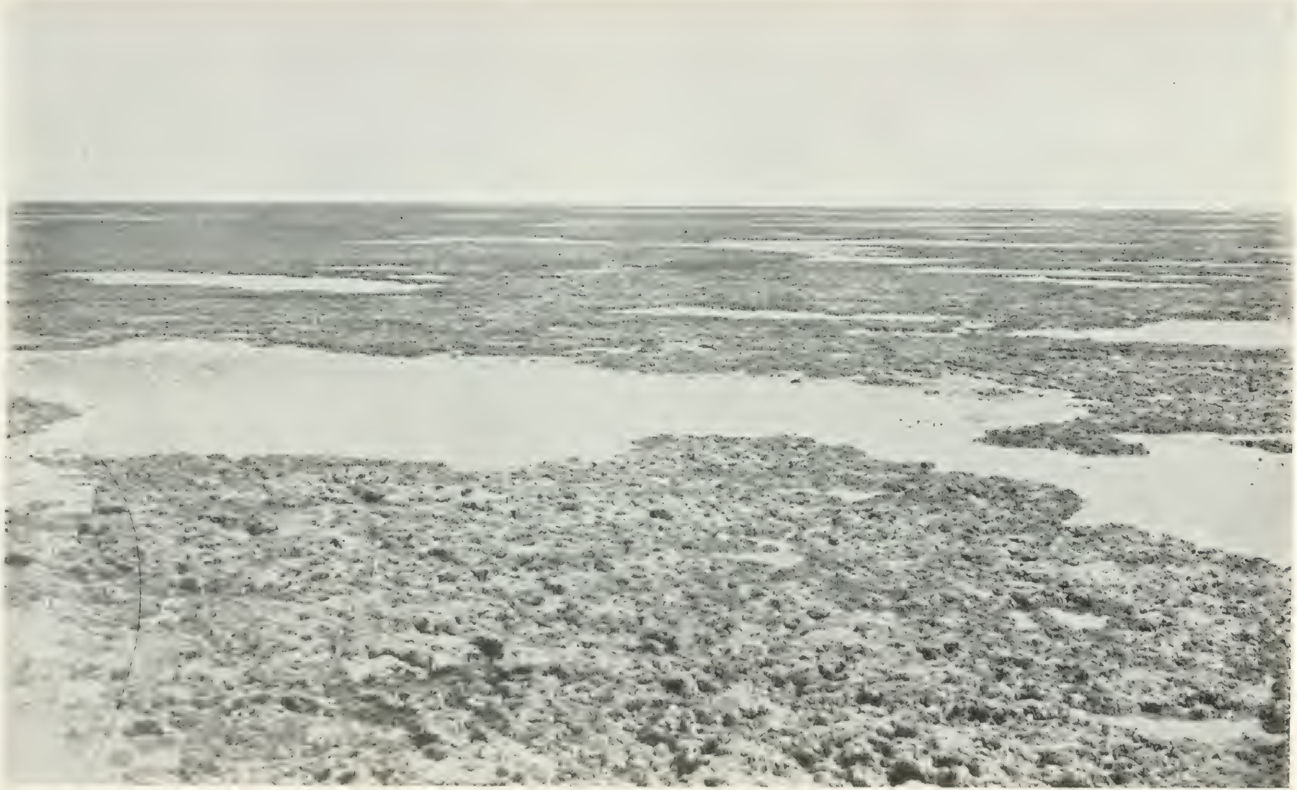
VIEW ON THE LIXA CORAL REEF.



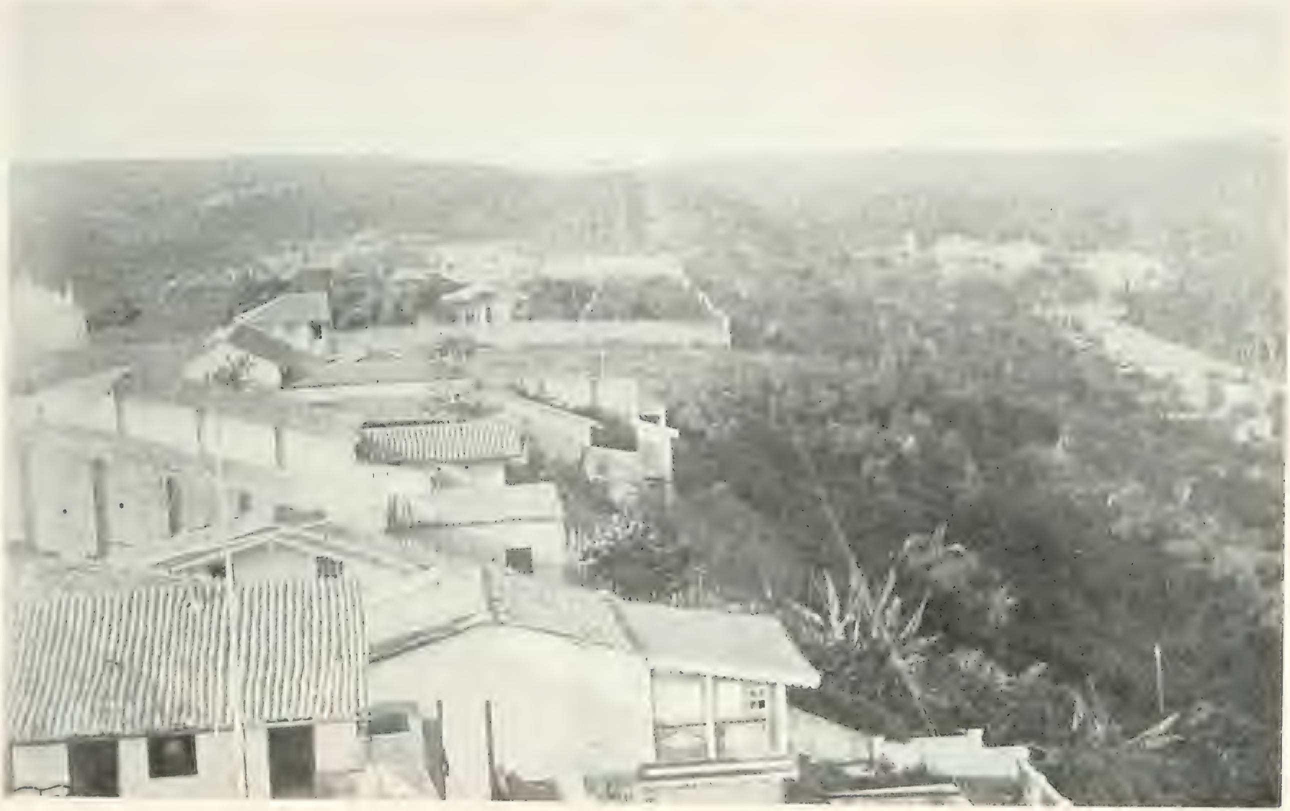
LIXA CORAL REEF NEAR THE NORTHERN END.



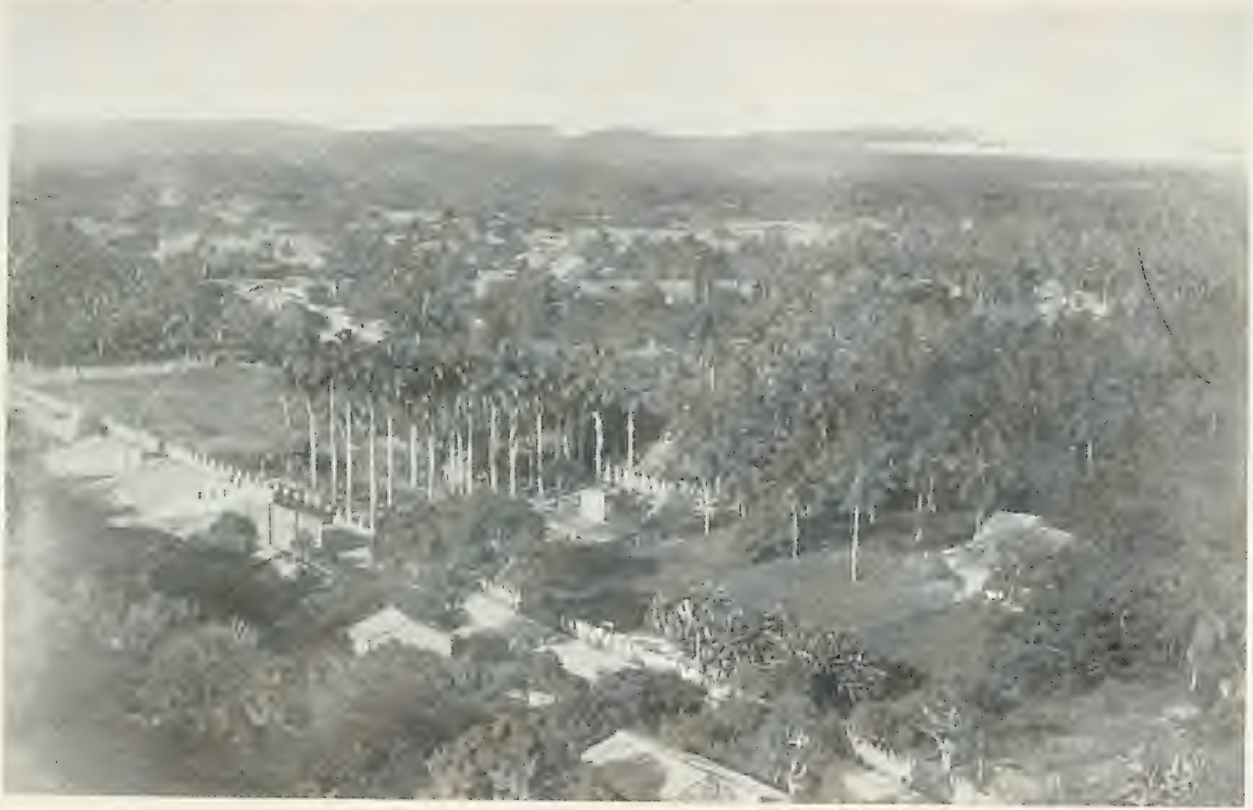
LIXA CORAL REEF AT LOW TIDE.



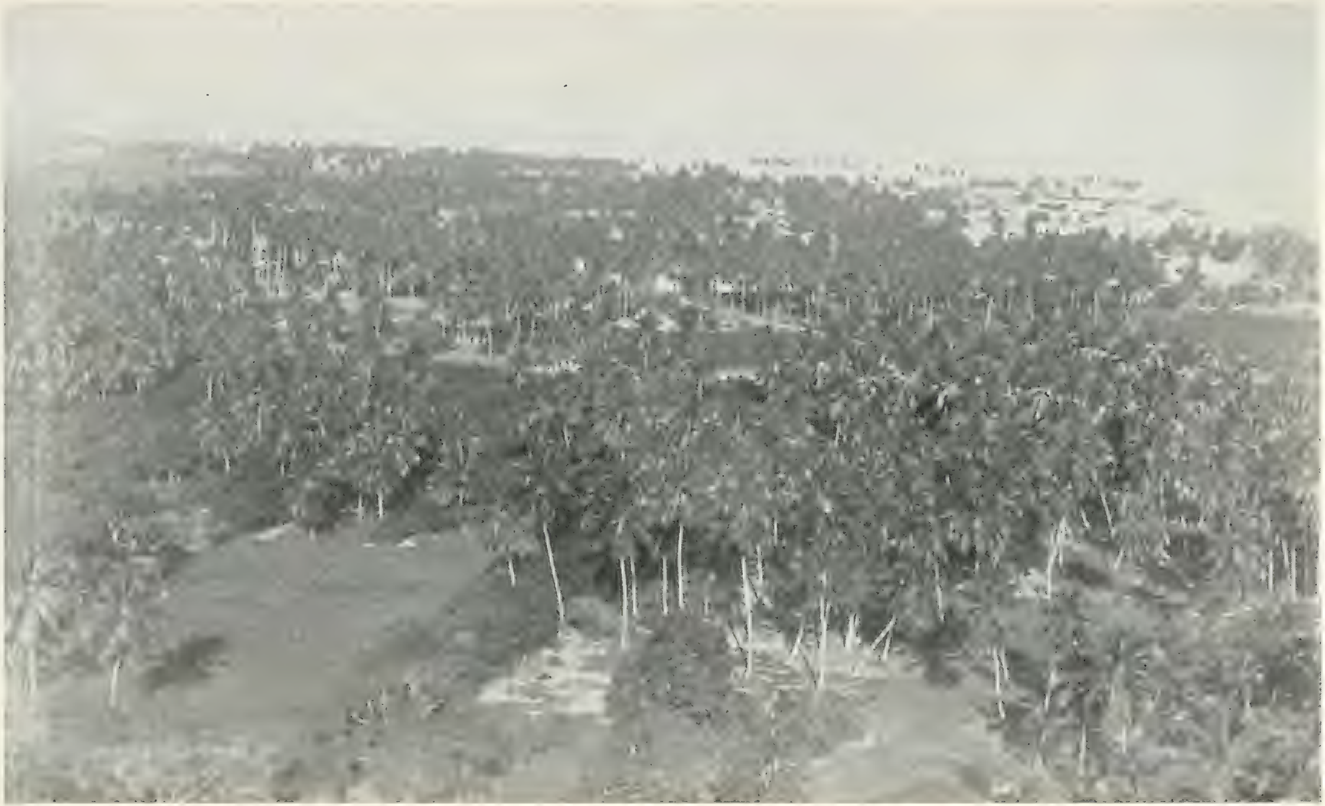
LIXA CORAL REEF.



NORTH COAST OF MACEIO.



NORTH COAST OF MACEIO.



NORTH COAST OF MACEIO.

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